EVALUATION OF PRECIPITATION ON THE MONTEREY PENINSULA

GALE MAURICE GRISWOLD

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by

Gale Maurice Griswold

Lieutenant (junior grade), United States Naval Reserve

Submitted in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE
IN
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PREFACE

The Monterey Peninsula located on the central coast of California is characterized by a 750 foot ridge through the center of the Peninsula. This ridge has a definite effect on the precipitation pattern which occurs over the Peninsula. It is the aim of this paper to describe the variations in the observed precipitation patterns and indicate the causes.

This study was conducted at the U. S. Naval Postgraduate School, Monterey, California, during the period March through May, 1958.

The writer wishes to express his appreciation for the assistance and encouragement given him by Professors C. L. Taylor and R. J. Renard of the Department of Aerology, U. S. Naval Postgraduate School and the suggestions and comments offered by Professor W. D. Duthie, Chairman, Department of Aerology, U. S. Naval Postgraduate School, in conducting this study and preparing this report. The writer also wishes to express his appreciation for the cooperation of the amateur observers, without whose help this study could not have been made.

ABSTRACT

An evaluation of precipitation on the Monterey Peninsula on California's central coast is of value in determining the effect of orographic barriers on rainfall. This study was made possible by the cooperation of numerous amateur observers located throughout the Peninsula.

A study of the precipitation patterns recorded over the Peninsula indicated that the factors affecting the precipitation included wind speed, wind direction, type of clouds, height of clouds and location as well as elevation of the recording station. Low clouds cause largest amounts of precipitation to occur at the base or on the slope to windward of the Peninsula ridge. Higher low clouds cause heaviest precipitation at the highest elevations with some areas of heavy precipitation to leeward of passes in the ridge.

The station which reports precipitation amounts closest to the average Peninsula precipitation was determined to be the Pacific Grove Reservoir. Class limit values used in forecasting amounts of monthly precipitation for the Monterey Peninsula were calculated for each month.

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1. Introduction

This study of precipitation measurements in Monterey County originated in October, 1957, with Professors R. J. Renard and C. L. Taylor of the Department of Aerology, United States Naval Postgraduate School, ~~they~~ and sharing a mutual interest in the study of rainfall on the Monterey Peninsula. Rainfall totals for various points on the Peninsula are printed in the Monterey Peninsula Herald* following each storm. These totals indicated that actual daily rainfall measurements were being recorded at various points on the Monterey Peninsula. It seemed probable that these observers would be willing to cooperate if a program were initiated to collect daily rainfall records for future study.

The cooperation of the Monterey Peninsula Herald was obtained in printing an article on the proposed program, stating its objective and asking all persons maintaining daily rainfall records to contact the Department of Aerology if they would like to participate in this collection program. Very favorable results were obtained from this publicity as 36 amateur rainfall observers indicated they would like to participate. These observers sampled an area from Moss Landing to Bixby Landing and included Seaside, Monterey, Pacific Grove, Pebble Beach, Carmel, Carmel Highlands, and Carmel Valley. The number of observers was deemed sufficient to begin collecting daily precipitation records by December 1957. The number of observers increased until the program had 38

*Monterey Daily Newspaper

active observers at the time of this writing with plans to add to this number in the future.

When it was decided that sufficient observers had been obtained to make a study of the variations in rainfall on the Monterey Peninsula feasible, a letter was distributed to all observers, inquiring as to the type and length of records which could be made available for such a study. As a result, the five-year records from July 1952 through June 1957 from 13 observers (Table I) were obtained. In addition to the study of five-year monthly and seasonal totals, the daily precipitation from 1 March 1958 through 6 April 1958 was also analyzed. This period of daily rainfall was chosen because of the large amounts recorded and also because of the numerous readings recorded from the amateur observers at this time. Three sets of long-period records were also made available for study and provided an opportunity for some limited analysis.

It is hoped that a study such as this will be undertaken in 1963 or later when five or more years of records are available from more observers. A much more detailed and enlightening study could then be undertaken.

The purpose of this study is to describe the effect of elevation, exposure, orientation, and time on the precipitation occurring on the Monterey Peninsula with a brief description of the precipitation pattern in the surrounding area. Due to the greater concentration of population on the Peninsula in comparison to the remainder of Monterey County,

Table I

Observers with Five-Year Records

Sta. No.	Location	Elev.	Exp.	Type of Gage
3	Monterey Sewage Plant, Del Monte Blvd.	40'	NW	Bendix, Self-reg.
6	U. S. Naval Air Facility, Monterey Airport	125'	NNW	Std. 4"
13	Hatton Rd., (Pt. of View), Carmel	240'	SW	Std. 8"
14	Carmel Valley Rd., Carmel Valley	40'	W	Std. 8"
18	San Clemente Dam, Carmel Valley	625'	N	Std. 8"
19	Los Padres Dam, Carmel Valley	900'	NNE	Std. 8"
22	Forest Lake, Pebble Beach	295'	W-NNE	Std. 8"
23	Del Monte Lodge, Pebble Beach	45'	S	Std. 8"
26	Near Pt. Joe and Bird Rock, Pebble Beach	60'	WSW-NNE	Wedge
27	Jewell Ave., Pacific Grove	40'	SW-NE	Std. 8"
30	David Ave. Reservior, Pacific Grove	243'	WNW-E	Std. 8"
31	Harrison St., Monterey	290'	N-E	Std. 8"
50	Bixby Mountain, Coast Hwy.	1500'	NW	Unknown

a reporting network of higher density is available, allowing a more detailed analysis to be made of the various parameters. Included in the final results are average or normal rainfall values for the Monterey Peninsula as determined from the available data and averages for each city where appropriate data are available.

This thesis will describe the location and accuracy of the cooperative observers and their instruments, the representativeness and methods of analyzing precipitation data, and present the results and conclusions drawn from the study. Recommendations for future research and evaluation are also included with the above material.

2. Cooperative Observers

It is obvious that when the cooperation of amateur observers is requested, it is impossible to designate the observation points such that they would be of the most value in the evaluation of precipitation over a large area. Instead, it is necessary to make as complete a study as possible with the data that is so willingly given, making necessary assumptions and extrapolating into unpopulated areas when data is questionable or missing. Some of the factors which are of interest concerning the cooperative observers include their location, reliability, maintenance of records, and the availability of their records.

The locations of the 28 observers whose data were used in the study of precipitation on the Monterey Peninsula are indicated on the topographic chart of the Peninsula (Fig. 1) by circled numbers. The address, elevation, exposure, and type of gage used by each observer is enumerated in Table II. The six observers enumerated in Table III are those in Monterey County not located on the Peninsula. Moss Landing is located at approximately the midpoint of the east side of Monterey Bay, this being the only observer north of the Peninsula at present. Records are made available by the California Water and Telephone Company for the two dams on the Carmel River, San Clemente and Los Padres Dams, located in the upper part of Carmel Valley. The other observers are located on the Coast Highway near Bixby Landing, well south

Table II

Peninsula Cooperative Observers

Sta. No.	Location	Elev.	Exp.	Type of Gage
2	Elm St., Seaside	30'	O	Wedge
3	Monterey Sewage Plant, Del Monte Blvd.	40'	NW	Bendix, self-reg.
4	Root Hall, USNPGS	40'	NNW	Navy auto. Wx. Sta.
6	U. S. Naval Air Facility, Monterey Airport	125'	NNW	Std. 4"
7	Del Monte Fairways, Monterey	175'	SE	Std. 4"
8	Jacks Peak, Monterey	700'	NE, SW	Wedge
9	Camino Del Monte @ Guadelupe, Carmel	400'	SSW	Wedge
10	Flanders Dr. @ Baldwin Pl., Carmel	150'	WSW	Wedge
11	Monte Verde @ 16th, Carmel (River Mouth)	20'	SW	Wedge
12	Carmel Hills Dr. (Near H.S.), Carmel	420'	SW	Homemade
13	Hatton Rd., (Pt. of View), Carmel	240'	SW	Std. 8"
14	Carmel Valley Rd., Carmel Valley	40'	W	Std. 8"
22	Forest Lake, Pebble Beach	295'	W-NNE	Std. 8"
23	Del Monte Lodge, Pebble Beach	45'	S	Std. 8"
25	Cypress Point Club, Pebble Beach	50'	SW-NNE	Unknown
26	Near Pt. Joe and Bird Rock, Pebble Beach	60'	WSW-NNE	Wedge

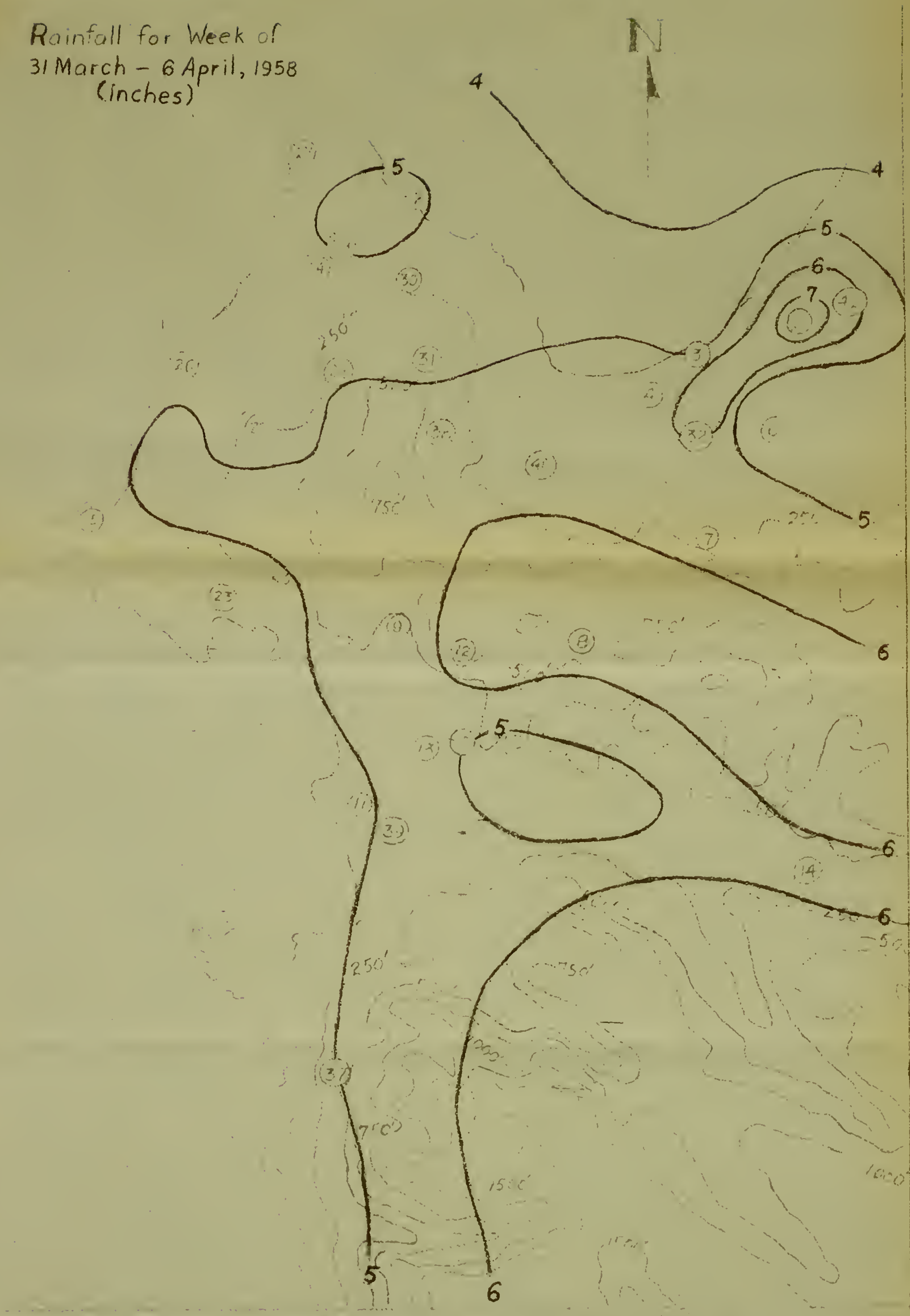

FIGURE 11. ISOHYET CHART FOR WEEK OF 31 MARCH-6 APRIL 1958

Table II

Peninsula Cooperative Observers

Sta. No.	Location	Elev.	Exp.	Type of Gage
2	Elm St., Seaside	30'	0	Wedge
3	Monterey Sewage Plant, Del Monte Blvd.	40'	NW	Bendix, self-reg.
4	Root Hall, USNPGS	40'	NNW	Navy auto. Wx. Sta.
6	U. S. Naval Air Facility, Monterey Airport	125'	NNW	Std. 4"
7	Del Monte Fairways, Monterey	175'	SE	Std. 4"
8	Jacks Peak, Monterey	700'	NE, SW	Wedge
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23	Del Monte Lodge, Pebble Beach	45'	S	Std. 8"
25	Cypress Point Club, Pebble Beach	50'	SW-NNE	Unknown
26	Near Pt. Joe and Bird Rock, Pebble Beach	60'	WSW-NNE	Wedge

Sta. No.	Location	Elev.	Exp.	Type of Gage
27	Jewell Ave., Pacific Grove	40'	SW-NE	Std. 8"
28	Funston Ave., Pacific Grove	360'	WSW-NNE	Sunset house
29	Alder St., Pacific Grove	130'	WNW	Victor
30	David Ave. Reservoir, Pacific Grove	243'	WNW-E	Std. 8"
31	Harrison St., Monterey	290'	N-E	Std. 8"
32	Oak Crest Circle, Joselyn Canyon Rd., Monterey	40'	N	Test tube
34	17 Mile Dr., Pacific Grove	140'	WNW	Test tube
37	Mt. Devon Rd., Carmel Highlands	400'	W-NW	Std. 4"
38	Toyon Heights, Monterey	360'	NE-ENE	Std. 4"
39	Mission Fields, Carmel	20'	W	Std. 4"
40	Cuesta Vista Dr., Monterey	170'	N-NNE	Std. 4"
42	Birch Ave., Seaside	30'	O	Std. 4"

Table III

County Cooperative Observers

Sta. No.	Location	Elev.	Exp.	Type of Gage
1	Pacific Gas & Electric, Moss Landing	30'	O	Std. 4"
18	San Clemente Dam, Carmel Valley	625'	N	Std. 8"
19	Los Padres Dam, Carmel Valley	900'	NNE	Std. 8"
20	Rocky Pt., State Hwy. #1	150'	WNW	Wedge
21	Palo Colorado Canyon (1.7 mi. from Hwy. #1)	630'	NW	Test tube
50	Bixby Mountain, Coast Hwy.	1500'	NW	Unknown

of the Peninsula. The locations of the observers by station number according to areas are as follows:

Seaside - 2, 42
Monterey - 3, 4, 6, 7, 8, 31, 32, 38, 40
Pacific Grove - 27, 28, 29, 30, 34
Pebble Beach and Country Club - 22, 23, 25, 26
Carmel - 9, 10, 11, 12, 13, 39
Carmel Valley - 14
Carmel Highlands - 37

Moss Landing - 41
Carmel Valley - 18, 19
Coast Highway - 20, 21, 50

The numbers are not consecutive due to the deletion of some observers when their records were no longer received. As some records are available for most of these observers, their numbers were not reassigned in hopes that they might wish to take part in the program again at a future date. Each observer is supplied forms on which to record each day's rainfall. These forms are returned to the Department of Aerology at the United States Naval Postgraduate School at the completion of each week during the rainy season. During the dry summer season, the observers are asked to send in forms only for the weeks when precipitation is observed.

All observations are taken at 0800 local time or as near this time as possible except the United States Naval Air Facility* at Monterey where records of observed rainfall are recorded at 0200, 1000, 1600, and 2200. The observations taken at 1600, 2200, 0200, and 1000 are totaled and recorded as the total rainfall for the day prior to the day of the 1000 reading. When an amateur observer is away for a weekend

*Hereafter referred to as USNAF.

or longer, he reads his rain gage at 0800 of the day following his return and records this amount as the total for the intervening days. This makes studies of daily rainfall difficult over weekends at times but usually does not affect the total monthly values unless the absence occurs over the first of the month. The accumulation of rainfall for two or more days has no effect on the seasonal totals from July to June as the rainfall is usually zero for either or both months and if rainfall occurred on a weekend, it would be very light. Yearly values possibly could be affected if rain fell on a weekend during which 1 January occurred as precipitation is frequently heavy during December and January.

The cooperative observers' reports are reliable to the extent of the accuracy of their equipment, barring human errors such as misreading the gage or neglecting to record the amount.

The daily rainfall records used in this report were obtained from the weekly forms sent in by each observer. The monthly totals used for the five-year analysis were obtained directly from the observers. The replies to a letter disseminated to all observers requesting information on the length and availability of their records indicated that five years was the longest period which could be studied without seriously limiting the number of reports. Thirteen (13) sets of records were obtained.

The seasonal period of July through June was chosen as an appropriate time interval rather than the usual period of

January through December because the rainfall during the summer months ranges from zero to ten hundreths. These months of little or no precipitation provide a convenient dividing period.

Though the observers are not positioned as well as could be desired and their records are not as complete as professional installations, their cooperation is commendable and their efforts sincere. If additional observers could be obtained in Pebble Beach and on the hillside in Monterey Country Club as well as both slopes of Carmel Valley and in Carmel Highlands, a very complete coverage of the Peninsula would result.

3. Precipitation Measuring Instruments

The precipitation reported by an observer is that amount which the rain gage contains. Since the observer must assume that this is the amount of precipitation which occurred at that location, a discussion of the types and accuracy of rain gages seems justified.

a. Types of Rain Gages. There are many types of rain gages available, each with its own advantages and disadvantages. The gages used by the observers reporting precipitation for this study include the Weather Bureau standard eight-inch, Navy standard four-inch, Bendix self-registering, tipping bucket, wedge, and test-tube type gages. Of these gages, the Bendix self-registering type should be the most accurate if properly installed. It measures the amount of water collected by continuously weighing the container and inscribing this weight on a time chart. When the amount of water reaches a certain level in the container, it is automatically siphoned off. A chance of error could arise if the siphoning process occurred during a period of light precipitation as the small amount of weight added by the light rainfall would not be sufficient to cause a fluctuation on the graph. The tipping bucket is a continuously recording rain gage also in that a counter is tripped each time the bucket contains 0.01 inches. This gage may show discrepancies when large droplets of rain occur which may tip the bucket before it is full because of their weight and velocity. The bucket has also been known to be tipped by a heavy gust of wind.

The standard eight-inch and four-inch gages are very accurate but must be read at given intervals. The eight-inch gage samples a larger area of rainfall and is, therefore, considered more accurate than the four-inch gage. The wedge-type gage has a one-inch square opening for collecting the precipitation and uses the sloping portion to magnify the amount collected. The test-tube type gage has an opening one-half inch in diameter, does not employ an amplifying system for reading the amount of water collected, and is therefore the least accurate of all the gages. One inch on the side of the test tube represents one inch of precipitation, which necessarily limits the least count of the gage to 0.1 inches. The standard eight-inch and four-inch gages as well as the wedge-type gage collect the precipitation over a larger area than that of the measuring column, upon which an appropriate scale is inscribed. This allows a smaller least count, usually of 0.01 inches.

b. Exposure. The most accurate rain gage may record an unrepresentative value if not properly exposed. If the gage is placed in a sheltered area such as beside a building, under a tree, or between two buildings, it will indicate a lighter rainfall than actually occurred unless the rain falls straight down. If the gage is placed near the eaves of a building, additional rain may be collected by splashing, running, or blowing water from the eaves. A rain gage between two buildings may collect more than the actual rainfall during a storm with high winds which could channel the precip-

itation between the two buildings. Needless to say, a gage should not be placed where lawn sprinklers might affect it.

An example of an accurate gage which gives inaccurate records because of its exposure is the rain gage located across Fifth Avenue from Root Hall on the United States Naval Postgraduate School grounds. While not located directly under a tree, it is close enough to be sheltered by it during storms with light to moderate winds and correspondingly records less precipitation than actually fell during the storm, but may record some precipitation after the storm if the wind blows water from the tree in the direction of the gage. For this reason, the records from this gage were not used in this study. The records from the tipping-bucket type gage mounted on the roof of Root Hall were used instead (No. 6).

For correct exposure, the rain gage must be mounted on a firm, level surface, with the collector ring level. The gage should be at least three to four feet above the ground to eliminate the effect of light ground breezes. The distance from the gage to a vertical obstruction should be no less than the height of the obstruction[1]. Even with correct exposure, all rain gages will not record the same precipitation when a strong wind is present. More precipitation will be blown over the mouth of smaller gages than over the mouth of a standard eight-inch gage.

The maintenance of rain gages of the non-recording type is very minor. The gage should be cleaned occasionally during the periods of no precipitation to prevent inaccurate

readings. Dust and dirt may cause the gage to record as much as 0.01 inches in excess. Recording-type gages should be serviced periodically as specified by the manufacturer.

An accurate and reliable rain gage properly exposed and maintained is the first prerequisite for representative precipitation records. Without this as a basis, the records might indicate relative changes in precipitation, but often even this is obscured in the inaccuracies of the measurements.

4. Evaluation of Precipitation Records

When a study of precipitation records is undertaken, it must be assumed that they are accurate and representative of the immediate area where they were recorded. If the accuracy is doubtful, little can be learned of variations of precipitation with such factors as elevation, exposure, wind, and other parameters. Three methods will be used to evaluate precipitation for the Monterey Peninsula and surrounding county. These methods, i.e.: statistical, graphical, and correlative, will be discussed and later used to present the results of this study.

a. Statistical. Included in statistical methods of evaluating data are means, averages, and deviations. Means and averages alone do not indicate the variations in the original data and can be very misleading. As an example, Arnold Court[7] calculated some average yearly rainfall values for California. He stated that the average for a three-year period ending in 1958 was 19.64 inches. A value very close to this, 19.46 inches, was obtained for a five-year average ending in 1904. A high value of 27.61 inches was obtained for the five-year period ending in 1944. Low values of 16.88 inches and 16.89 inches were obtained for five-year periods ending in 1949 and 1934 respectively. Thus, it is quite evident that the average value for a given period will depend upon the deviations from the normal or long-term mean values as well as the average values of a period. The longer the period averaged, the less effective are very high or low

values in changing the average. However, if too long a period is averaged, a gradual change in values throughout the period may be eliminated. If precipitation were increasing slightly during the last ten years and an average of the last 60 years were calculated, it would be difficult to evaluate such a change. However, if two or three 20-year periods were averaged, the last 20-year average should show an increase over the first or second 20-year average.

Averages covering large areas sometimes lose their meaning. An average rainfall value for California gives no information as to the rainfall that occurred specifically either in northern or southern California. It is well known that northern California gets considerable precipitation while some of the deserts in southern California get little, if any.

b. Correlative. A number of studies have been made correlating topography and precipitation. Two of these, one for northern California[2] and one for western Colorado[3], provided methods by which a mean rainfall value could be obtained for any location. By combining three or four correlation graphs, the mean rainfall for 11 years converted to hourly intensity could be entered on one graph and by knowing the elevation, slope, orientation, and exposure, an intensity was arrived at that considered all of these factors. The value of these mean intensities is somewhat questionable in that the number of days of rainfall must be known for the station before a monthly or yearly value can be obtained.

In addition, only a mean value is obtained and the actual precipitation for a given period could vary widely from this mean.

c. Graphical. The results of this study are primarily presented in graphical form. Precipitation totals are plotted on graphs for comparative purposes for the various periods. To better delineate the variation of precipitation with elevation, lines of equal rainfall values (isohyets) are drawn on a topographic chart of the Monterey Peninsula for these same periods. The isohyet charts illustrate the variation of precipitation with elevation and location more effectively than descriptions or graphs.

5. Evaluation of Monterey County Precipitation Records

Analysis of the data in graphed and charted form indicates numerous variations, as would be expected. Only a few of the variations cannot be explained by physical or dynamic considerations and therefore must be attributed to instrument or human error. The discrepancies which have been attributed to errors will be pointed out in the discussion of the graph or chart on which they occur. The results of the analysis of the Monterey Peninsula data will be described with reference to graphs and charts for (a) three individual storms, (b) one seven-day period, (c) the total March 1958 precipitation and (d) the five-year seasonal means. In addition, the Monterey County data variations will be described for the same periods of time. The isohyet charts for the Peninsula are shown without individual rainfall values. The rainfall for any observer may be obtained from the appropriate graph or data sheet. The synoptic situations present for the three storms were taken from the USNAF charts drawn for the times indicated.

a. Individual Storms. During the first week of March 1958, rainfall occurred on 3, [illegible], and 7 March with little or no precipitation occurring on 2, 4, and 6 March. This provided three well-isolated storms which allowed analysis of the rainfall over the Peninsula for the effect of wind, topography, and exposure. On 3 March, the surface synoptic pattern was as shown in Fig. 2. A low-pressure center was moving down the California coast and towards the ocean. The

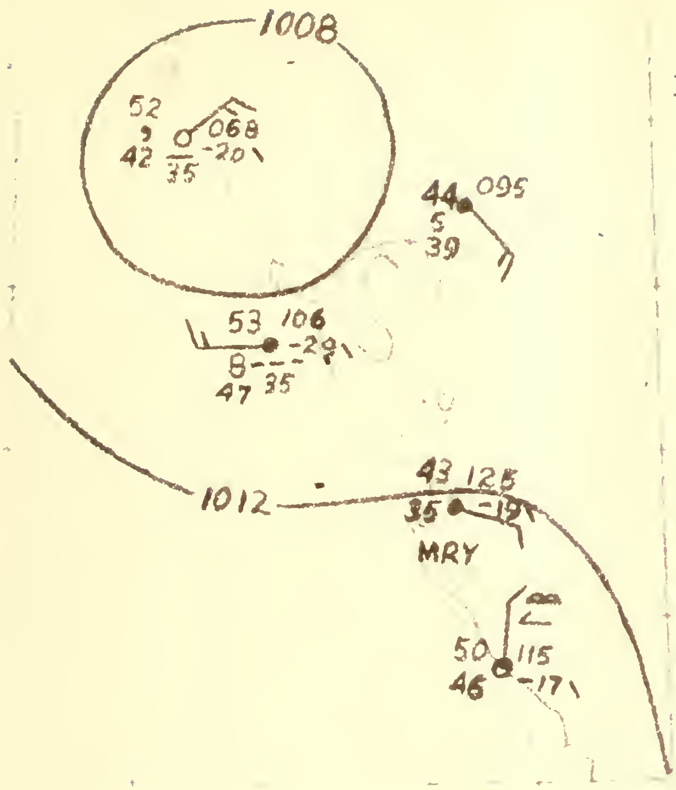
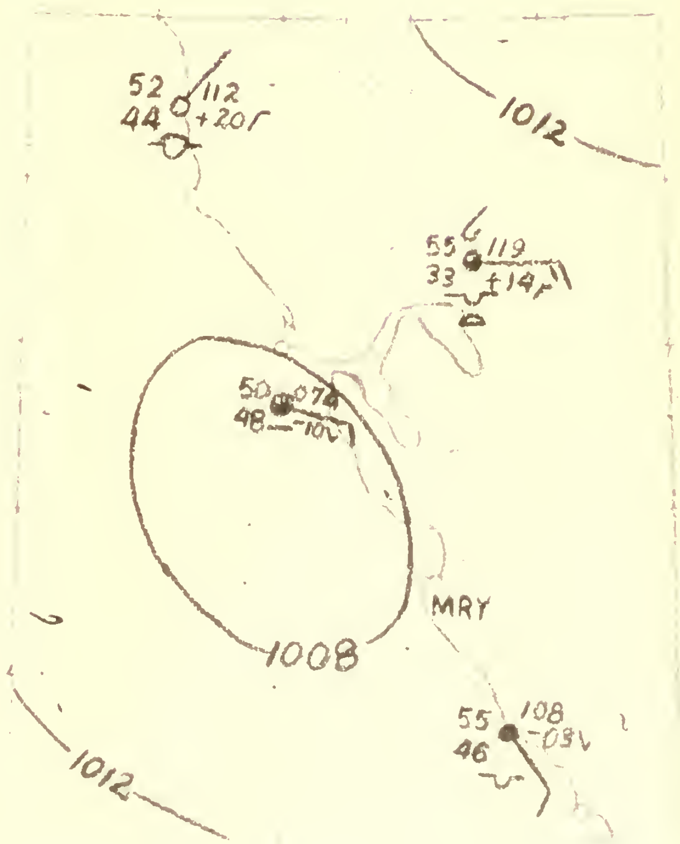


FIGURE 2 (a). SFC. CHART FOR 0400 PST 3 MARCH 1958

FIGURE 2 (b). SFC. CHART FOR 1000 PST 3 MARCH 1958



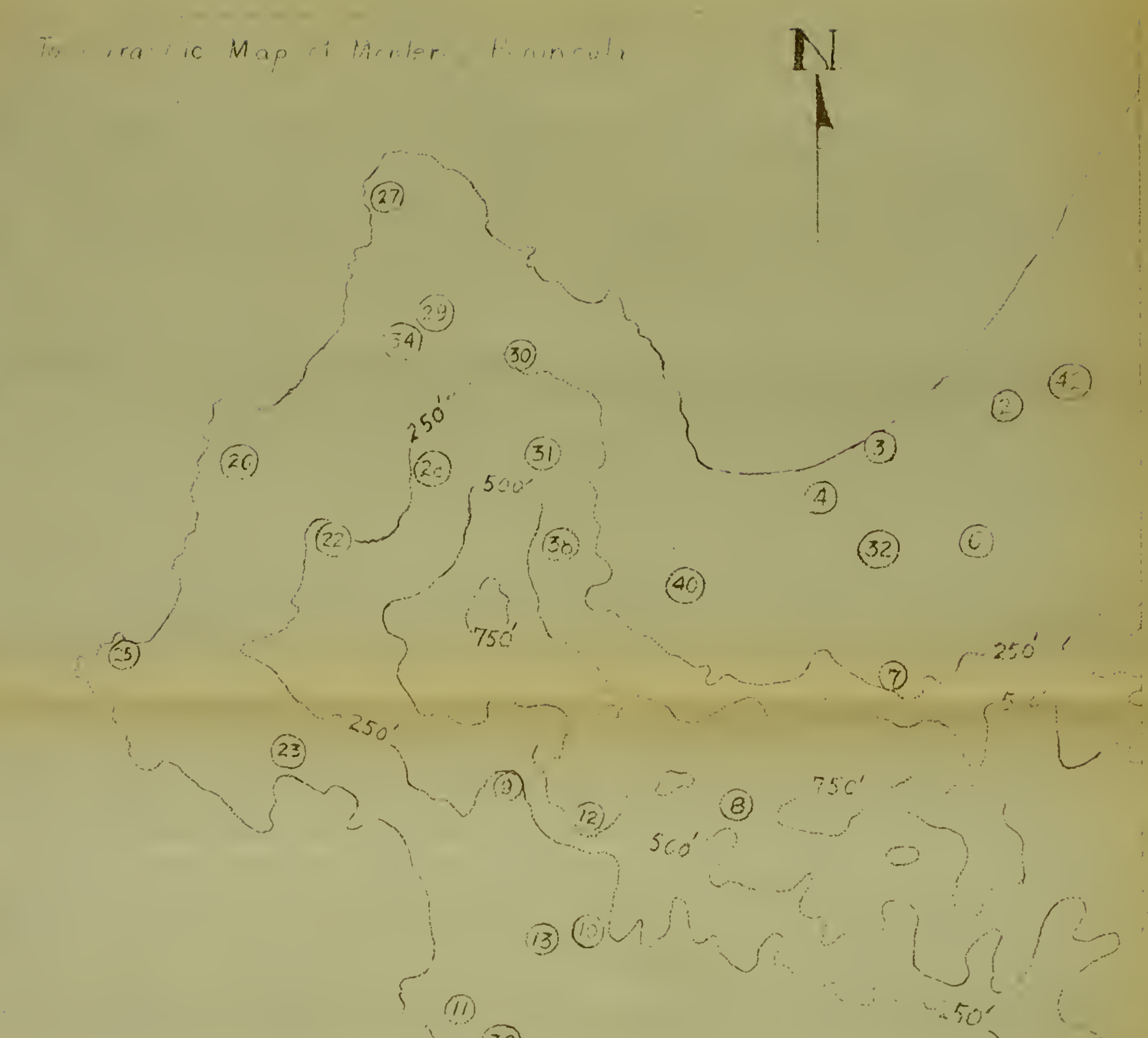


FIGURE 1. LOCATION OF COOPERATIVE OBSERVERS

average wind recorded at the USNAF during the period of precipitation was SSW at nine knots. The pattern of rainfall which occurred during this storm is indicated in Fig. 3. The steep slope along the coast of Carmel Highlands (No. 37) seemed to have a marked effect on the incoming flow, forcing the moist air up and over or around the 1500 foot ridge. This vertical motion either initiated or intensified the precipitation and caused an area of relatively high rainfall extending NNW across the mouth of Carmel Valley (No. 39). This high-rainfall area was restricted to elevations below 500 feet as less precipitation was observed at higher elevations on the 750 foot ridge of the Peninsula. The Peninsula ridge has an effect similar to that of the Carmel Highlands but to a lesser degree as may be seen by the deviation of the 0.40 inch line from the height contours at Monterey (No. 40). A steady decrease is evidenced northward along the shore as the influence of the ridge decreases. The low values of precipitation recorded on the west (windward) side of the Peninsula are a result of no orographic barriers to cause vertical motion and increase the precipitation.

The rainfall totals reported by each observer for 3 March are graphed in Fig. 4 and the averages for each city as well as the Peninsula are indicated. Seaside averaged 0.01 inches, Monterey 0.30 inches, Pacific Grove 0.52 inches, Pebble Beach 0.44 inches, and Carmel 0.52 inches as compared to the Peninsula average of 0.36 inches.

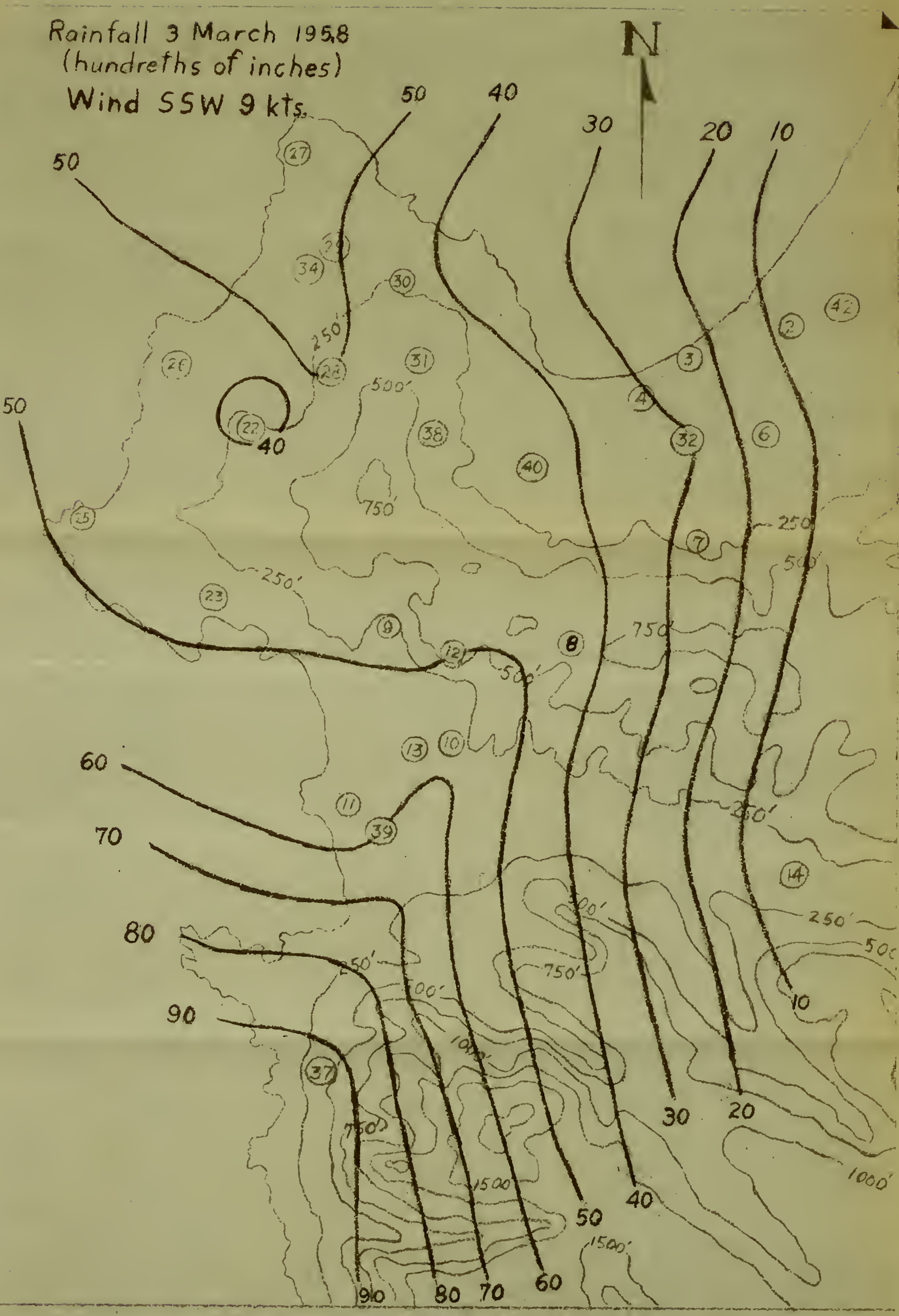


FIGURE 3. ISOHYET CHART FOR 3 MARCH 1958

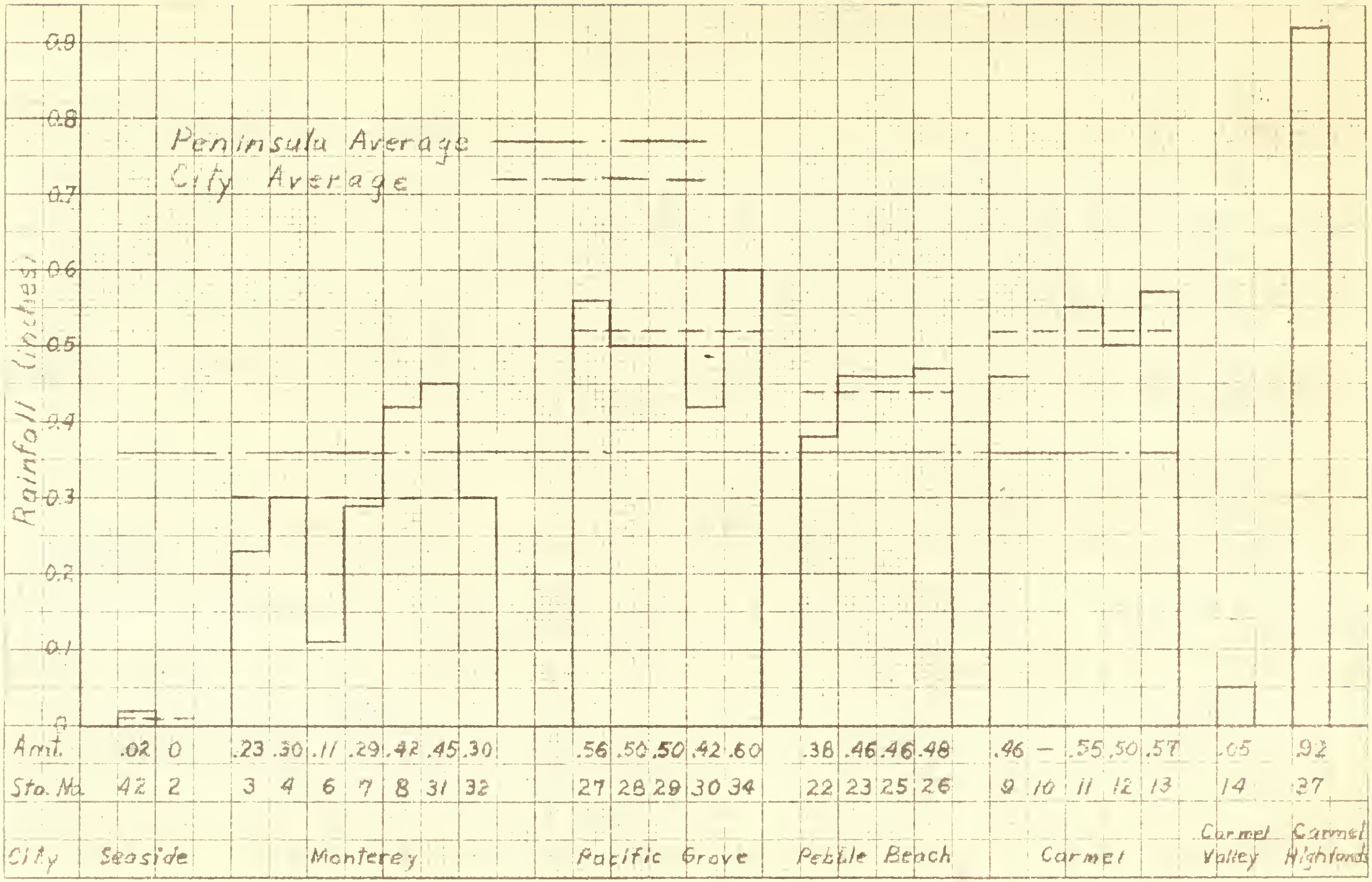


FIGURE 4. PRECIPITATION RECORDED FOR 3 MARCH 1958

The surface synoptic situation for the rainfall recorded on 5 March is indicated in Fig. 5. A cold front moved down the coast, passing over the Peninsula at 2300 PST. The average wind reported by the USNAF for the period of precipitation was WNW at eight knots with gusts to 21 knots. The rainfall pattern is depicted in Fig. 6, the amounts ranging from 0.0 to 0.20 inches. The minimum precipitation occurred on the windward, NNW, shore of the Peninsula and generally increased SSW with the slope of the terrain. Minimums are indicated at Pacific Grove (No. 34) and Monterey Beach (No. 3) with a maximum at Seaside (No. 2). The minimum near the tip of the Peninsula (No. 34) was due to the lack of orographic lifting, this being an area of low elevation on the windward side. The heavy amounts of precipitation recorded in Seaside are explained by localized showers from cumulus cloud formations. There are no orographic barriers to the windward of this area. The area of light precipitation in Carmel (No. 9) occurs in a small sheltered canyon. Carmel Valley received a relatively light amount as it is oriented in the direction of the wind. The heavier precipitation at the mouth of Carmel Valley can also be explained by cellular cumulus activity along the cold front. Fig. 7 indicates the respective amounts of precipitation reported by each observer for 5 March, 1958, and the averages for each city as well as the Peninsula average. The Peninsula average was 0.08 inches while Seaside averaged 0.20 inches, Monterey 0.06 inches,

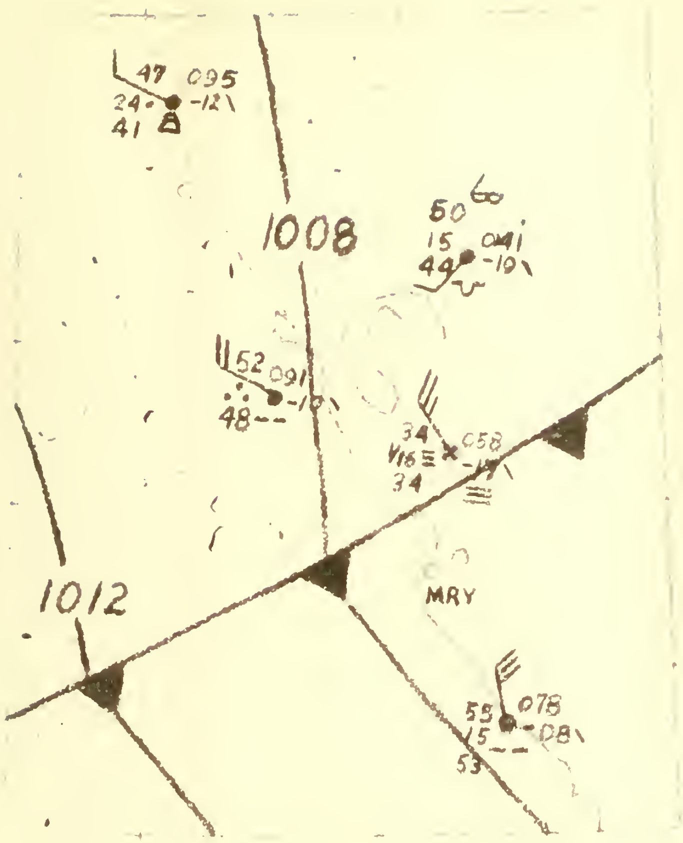
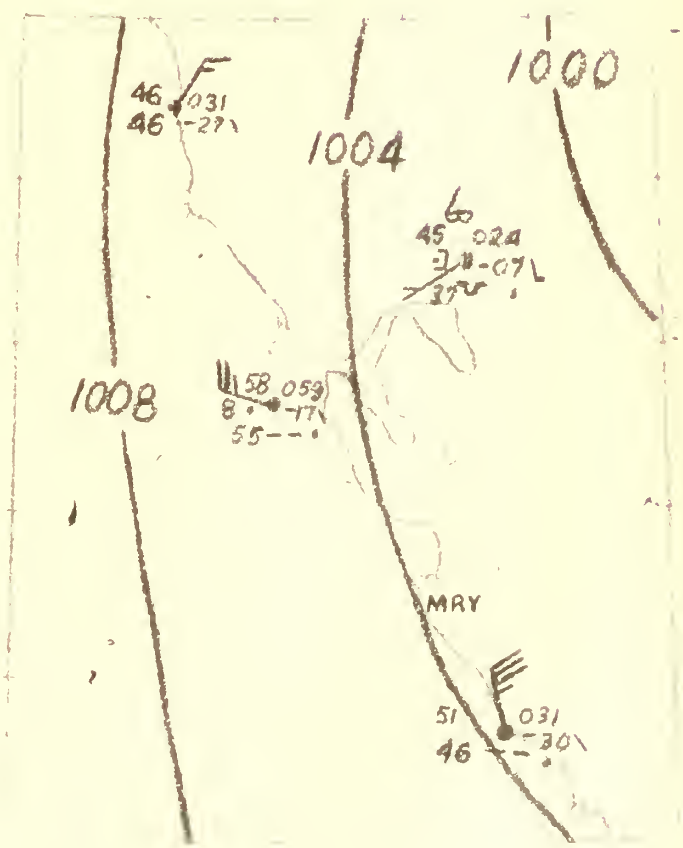


FIGURE 5 (a). SFC. CHART FOR 2200 PST 5 MARCH 1958

FIGURE 5 (b). SFC. CHART FOR 0400 PST 6 MARCH 1958



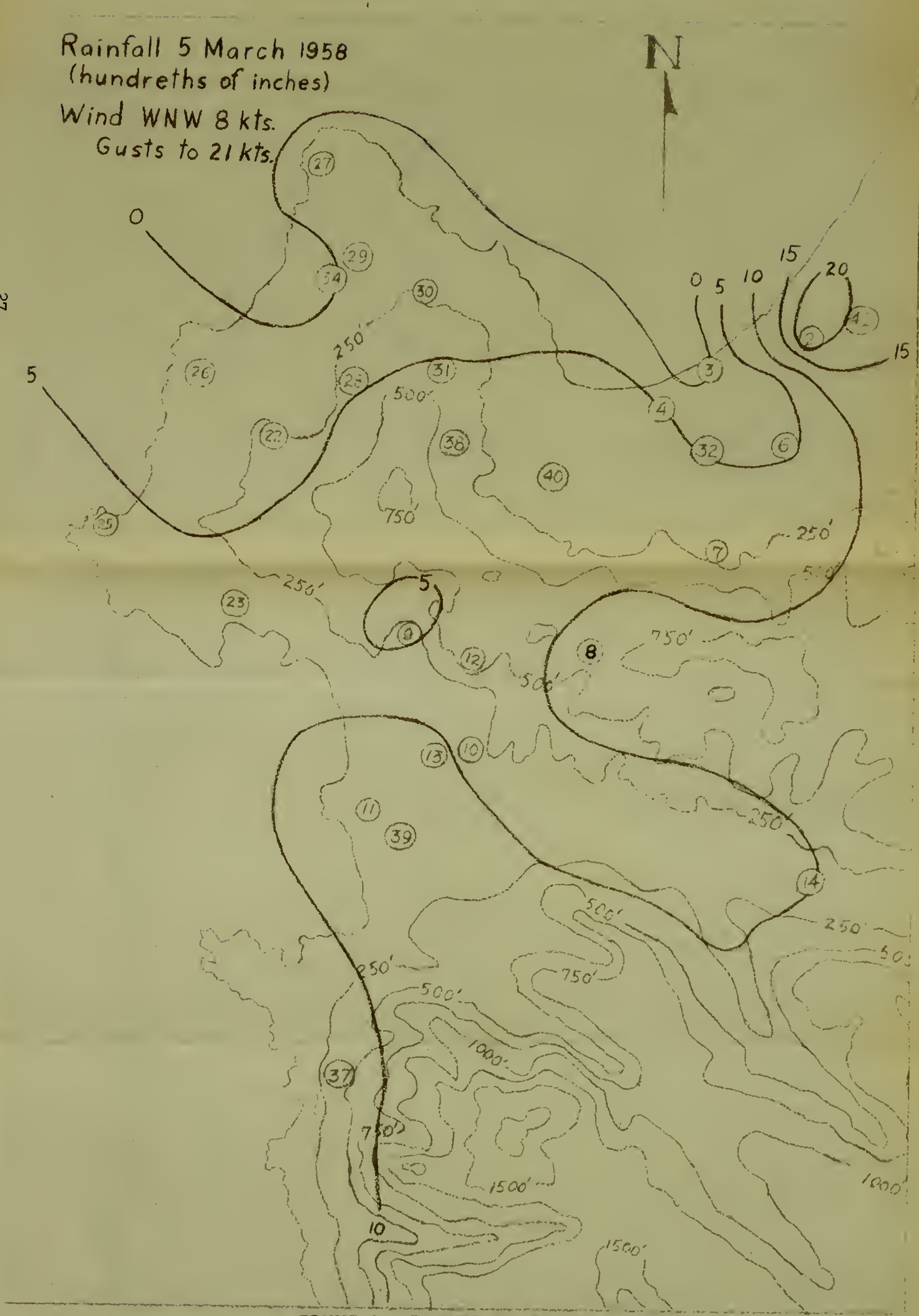


FIGURE 6. ISOHYET CHART FOR 5 MARCH 1958

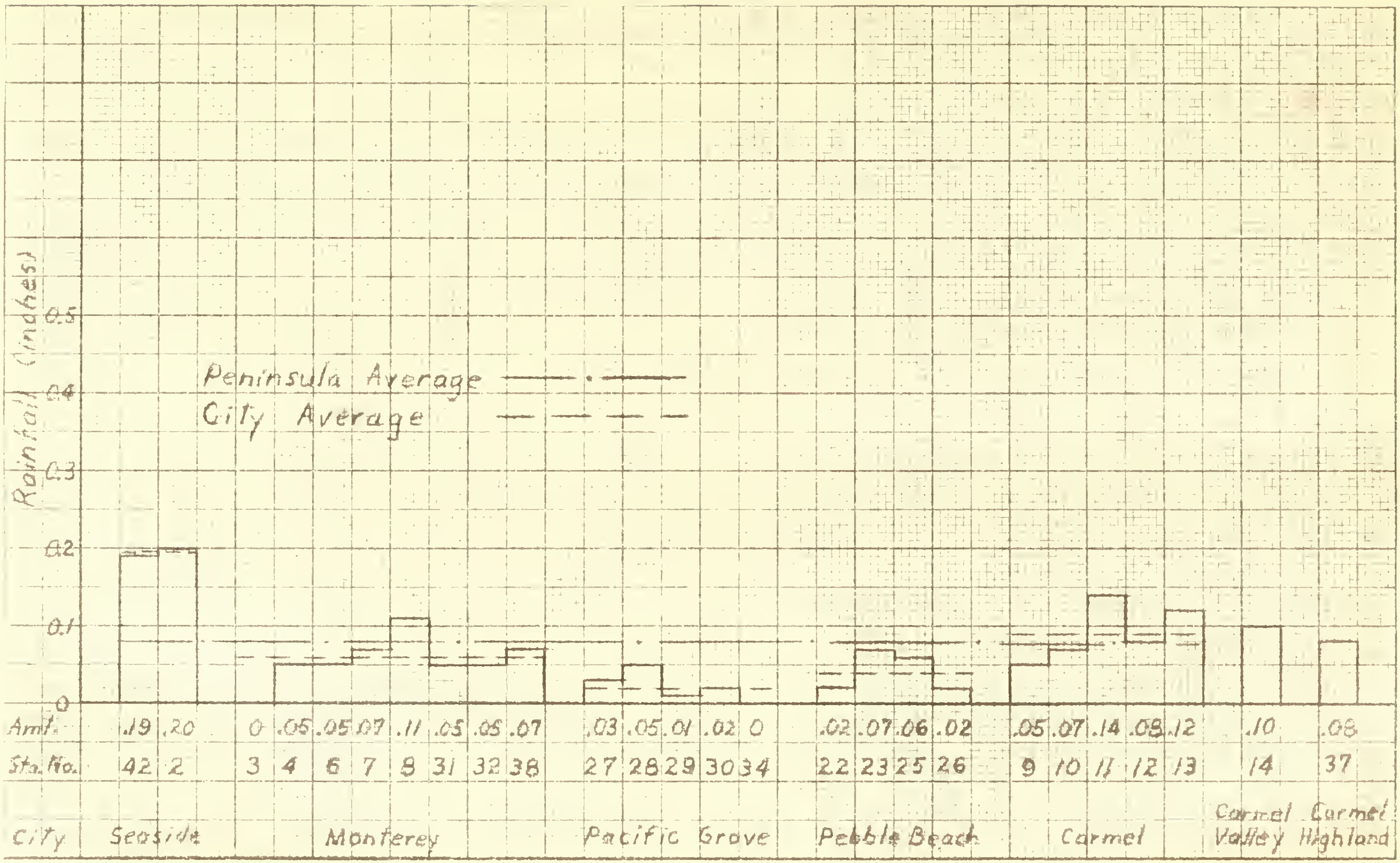


FIGURE 7. PRECIPITATION RECORDED FOR 5 MARCH 1958

Pacific Grove 0.02 inches, Pebble Beach 0.04 inches, and Carmel 0.09 inches.

The storm of 7 March 1958 caused precipitation measuring from 0.05 to 0.22 inches to occur over the Peninsula, as indicated by the isohyet chart, Fig. 8. The surface synoptic situation for this day is shown in Fig. 9. A cold front again moved down the coast, passing over the Peninsula at approximately 0100 PST on 8 March. The winds reported by the USNAF indicated a two-knot south wind prior to the frontal passage and a 14-knot SW wind after the front passed. A variation in rainfall from 0.05 inches on the north side of the Peninsula to 0.22 inches at Carmel Beach and Pebble Beach (No. 23) are noted on the isohyet chart. This variation with the heavy precipitation on the windward side is opposite to that observed in the storms of 3 and 5 March. It is possible that the precipitation came from clouds below 1000 feet. In this case, most of the water would have been extracted as the clouds passed over the 750 foot ridge of the Peninsula, leaving less to fall on the leeward side. This would explain the large amounts recorded on the windward side and the relatively larger amounts reported in Seaside would be a result of the 600 foot pass through the ridge. The clouds would not be lifted as much as at the other points along the ridge, leaving more precipitation to fall beyond the ridge. Fig. 10 shows that on 7 March, 1958, Seaside averaged 0.08 inches, Monterey 0.10 inches, Pacific Grove 0.09 inches, Pebble Beach

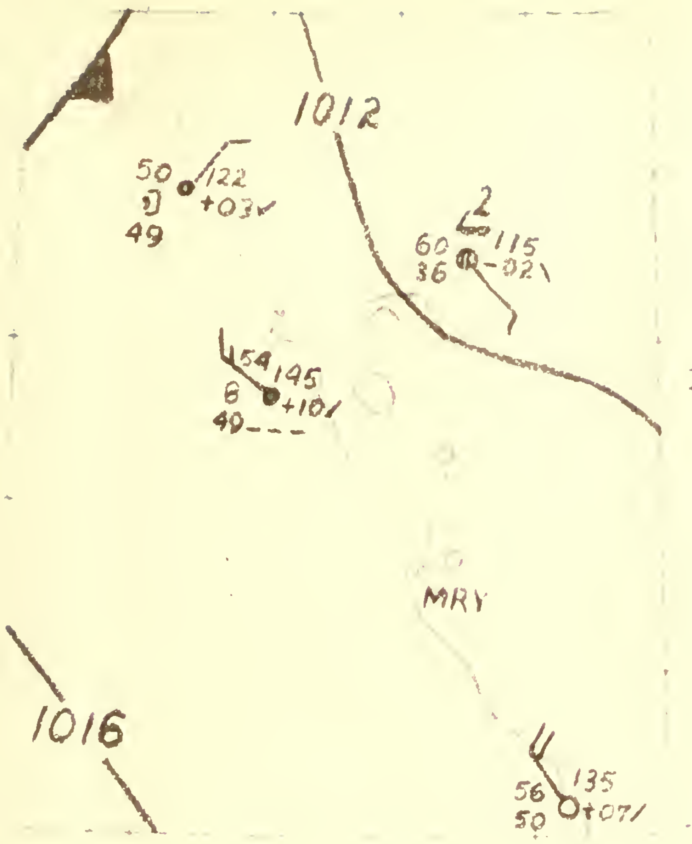


FIGURE 8.(a). SFC. CHART FOR 1600 PST 7 MARCH 1958

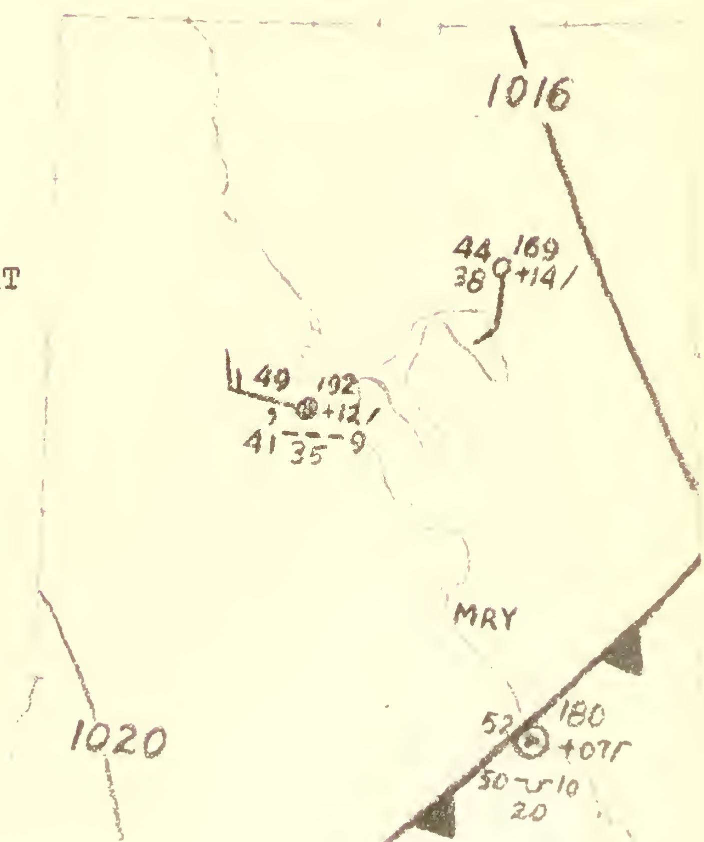


FIGURE 8 (b). SFC. CHART FOR 0400 PST 8 MARCH 1958

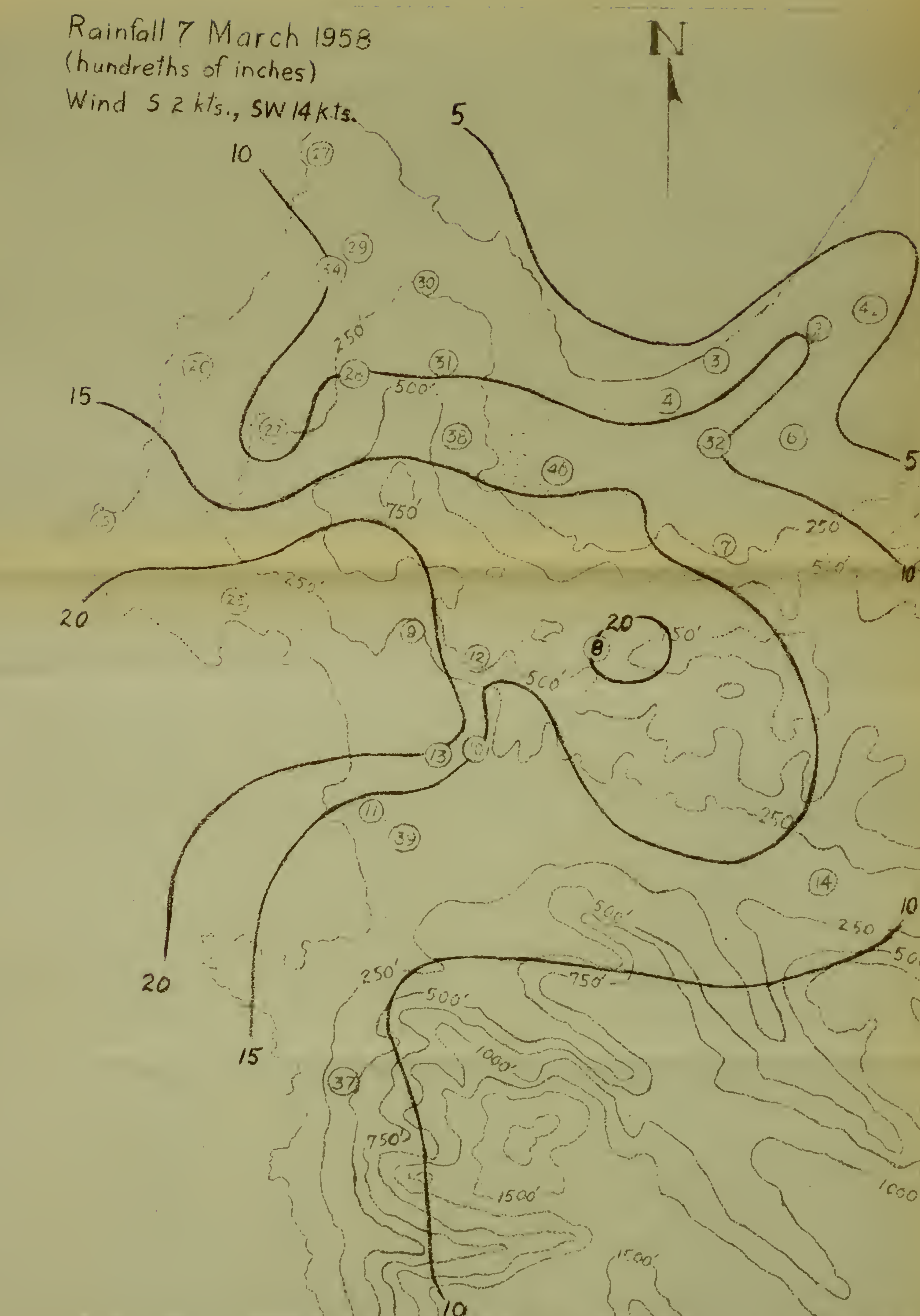


FIGURE 9. ISOHYET CHART FOR 7 MARCH 1958

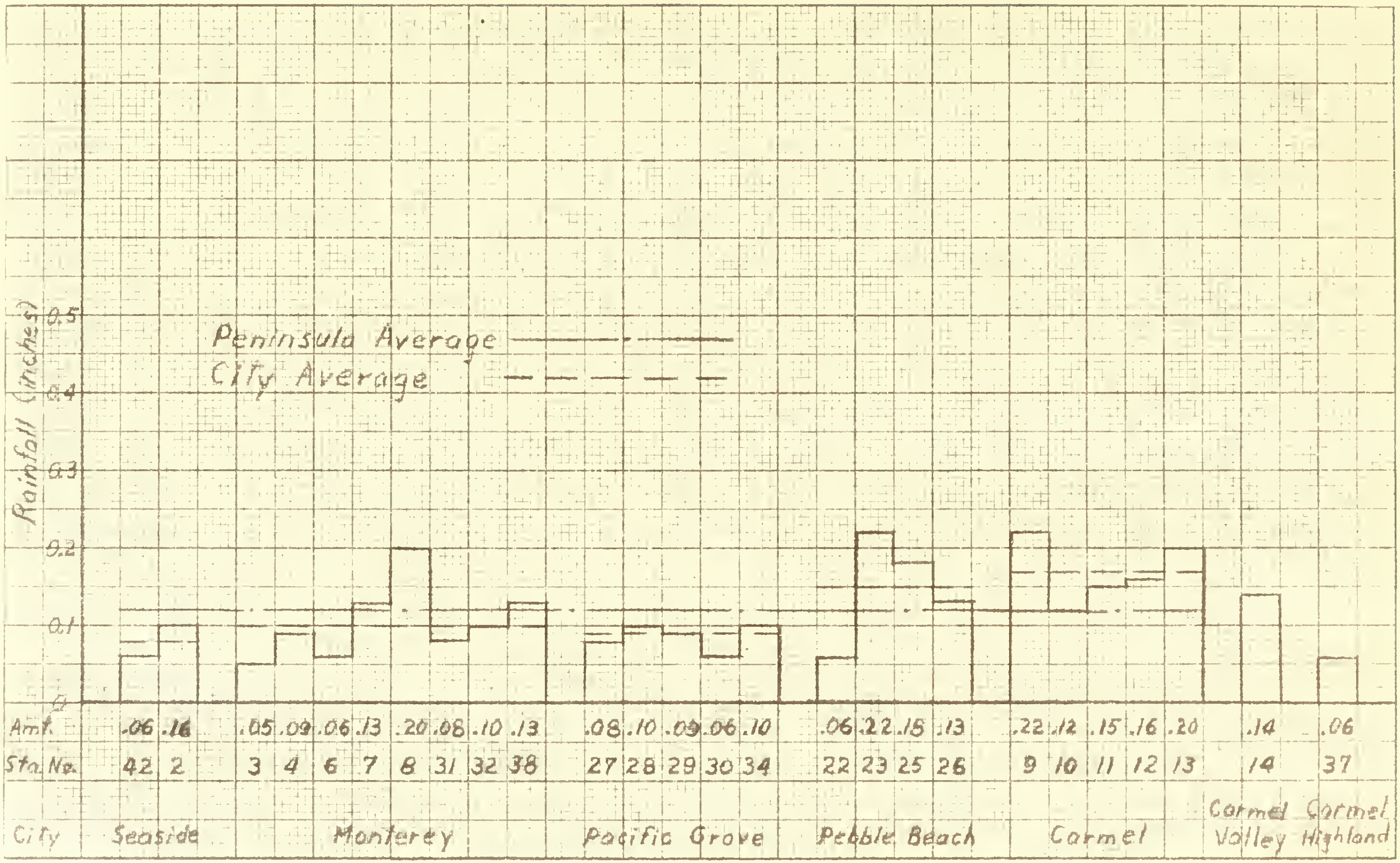


FIGURE 10. PRECIPITATION RECORDED FOR 7 MARCH 1958

0.15 inches, and Carmel 0.17 inches while the Peninsula as a whole received an average of 0.12 inches.

Factors which affect precipitation on the Monterey Peninsula include the wind speed, wind direction, type of cloud causing precipitation, and height of clouds capable of causing precipitation. The topography of the Peninsula has a marked effect on the amounts of precipitation received in any area. The effect of orographic lifting on rainfall is well described by V. Conrad[4]. He states that heavy precipitation may continue on the lee side of a mountain because of the continued upward movement of the ascending current due to the inertia of the air. When strong descending currents encounter this inertia driven air, the air is forced down and condensation ceases. This explains the gradual decrease in precipitation beyond the leeward side of the mountain. Heavy precipitation may also be evidenced some distance to windward of the mountain. This is caused by the stagnation of air against the mountain in the lower layers creating ascending air currents well to the windward side of the mountain. This effect was observed for the storm of 7 March, 1958. The heaviest rainfall occurred along Carmel Beach and Carmel, with decreasing amounts farther up the slope.

b. Seven-Day Period. The highest monthly total rainfall recorded since December, 1955, which was an exceptionally high month resulting in floods for many cities along the California Coast, was the month of March, 1958. Slight flooding was experienced from the rains during March, 1958,

for some cities along the coast. Carmel River banks and the area surrounding El Estero Lake in Monterey received minor flooding. The week of 31 March through 6 April 1958 was the week of heaviest rain. Observers reported rainfall for all seven days with over one inch per 24-hour period reported on two occasions and on three occasions for some observers.

The isohyets for the week of 31 March through 6 April are shown in Fig. 11. The totals for the week range from 4.0 inches to 7.6 inches. The general pattern is oriented NW - SE with the lower amounts on the northwest coast of the Peninsula. Higher elevations received the most precipitation except that the low area of Seaside (No. 2) reported the largest amount recorded on the entire Peninsula. This value seems out of proportion and may be due to improper exposure of the rain gage. The relative low values reported for Carmel Valley seemed quite representative considering the storm patterns described previously. The graphed values for each observer (Fig. 12) indicate the range and averages for each city as well as for the Peninsula. The Peninsula average for this one week was 5.08 inches, more than for most months of the year. Seaside averaged 5.34 inches, Monterey 5.19 inches, Pacific Grove 5.01 inches, Pebble Beach 4.48 inches, and Carmel 5.36 inches.

c. March. The rainfall for March was five times as heavy as the average March rainfall for the last five years and three and one-half times as heavy as the 23-year average from the old Del Monte Hotel [5]. Isohyets for March 1958 are

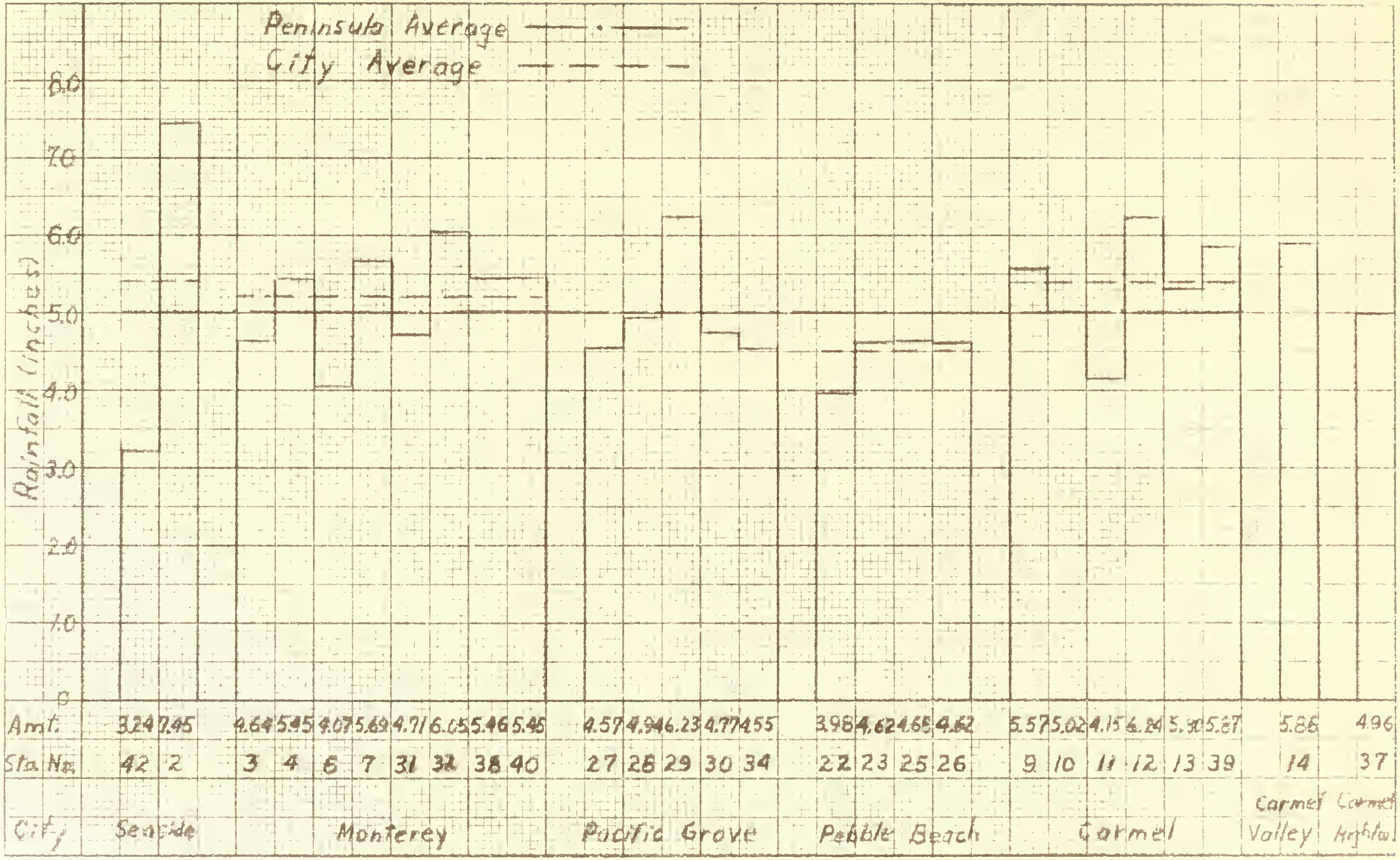


FIGURE 12. TOTAL PRECIPITATION RECORDED FOR 31 MARCH - 6 APRIL, 1958

shown in Fig. 13, which may be compared to the isohyets for an average of March totals from 1953-1957 (Fig. 14). The 1958 March chart is more detailed since data from 27 observers were available whereas the five-year average chart was drawn from nine reports. There is very little similarity between the two charts. The March, 1958 chart reflects the orographic effects of the ridge for SW winds, which is the wind direction during a majority of the storms. The five-year average chart for March shows heavier precipitation for higher elevations, except for the maximum of 2.0 inches on the northwest shore. Fig. 15 is a graph of the total rainfall for March 1958 for each observer. The averages for each city and the Peninsula can be compared to the variations in individual values. Seaside's average total precipitation for March was 6.45 inches, Monterey averaged 7.25 inches, Pacific Grove 8.27 inches, Pebble Beach 8.61 inches and Carmel 8.13 inches.

d. Five-Year Means. The five-year average for the season July 1952 through June 1957 was calculated for eight observers from their monthly records (Fig. 16) and the results plotted as a five-year mean chart (Fig. 17). This chart indicates a variation with elevation even more pronounced than the chart for March, 1958 (Fig. 13). The values range from 12.77 inches on Monterey Beach (No. 3) to 17.16 inches in Monterey (No. 31). Carmel Valley (No. 14) delineated the minimum values for the lower elevations and the continuation of the isohyets to indicate larger rainfall totals

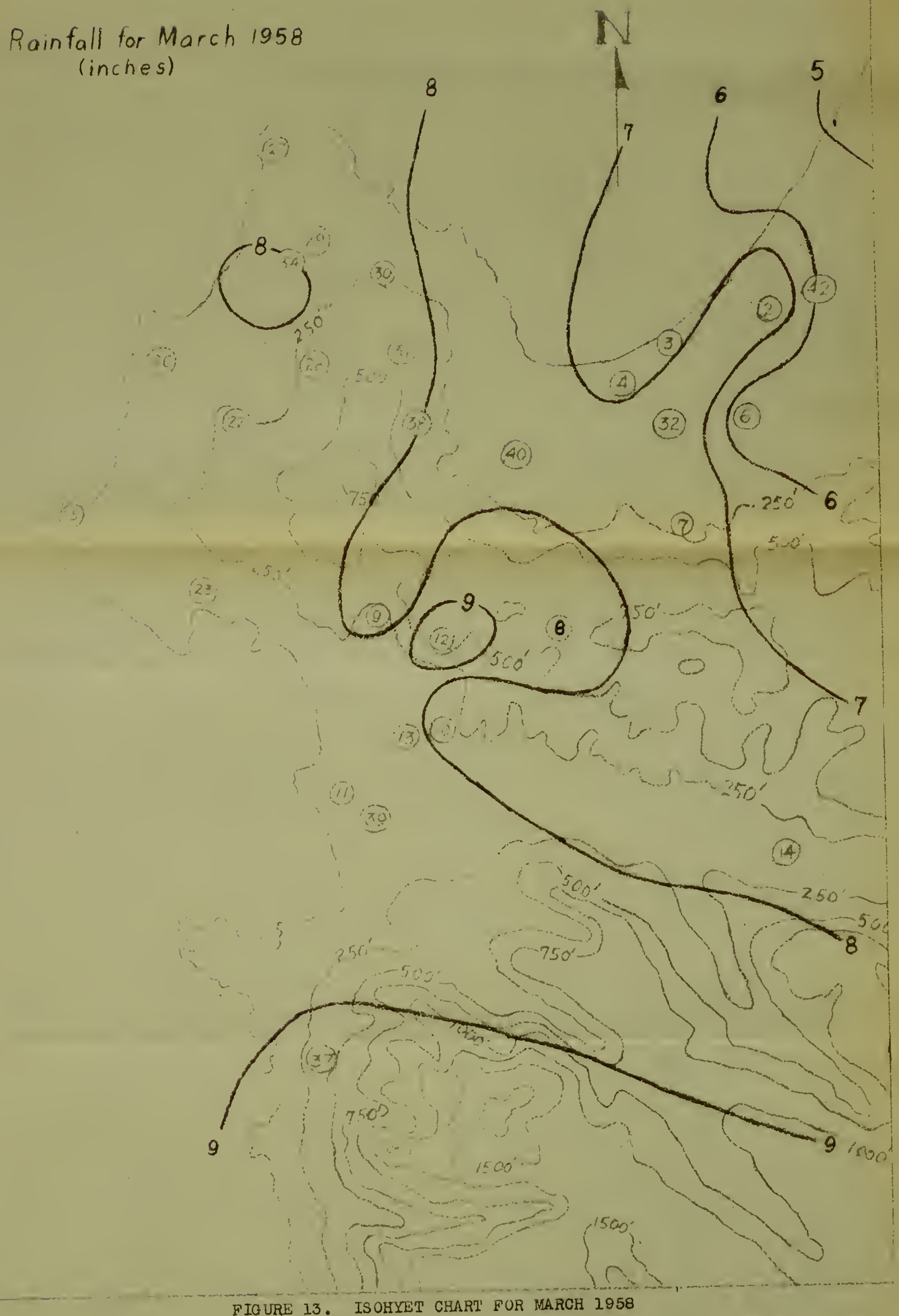


FIGURE 13. ISOHYET CHART FOR MARCH 1958

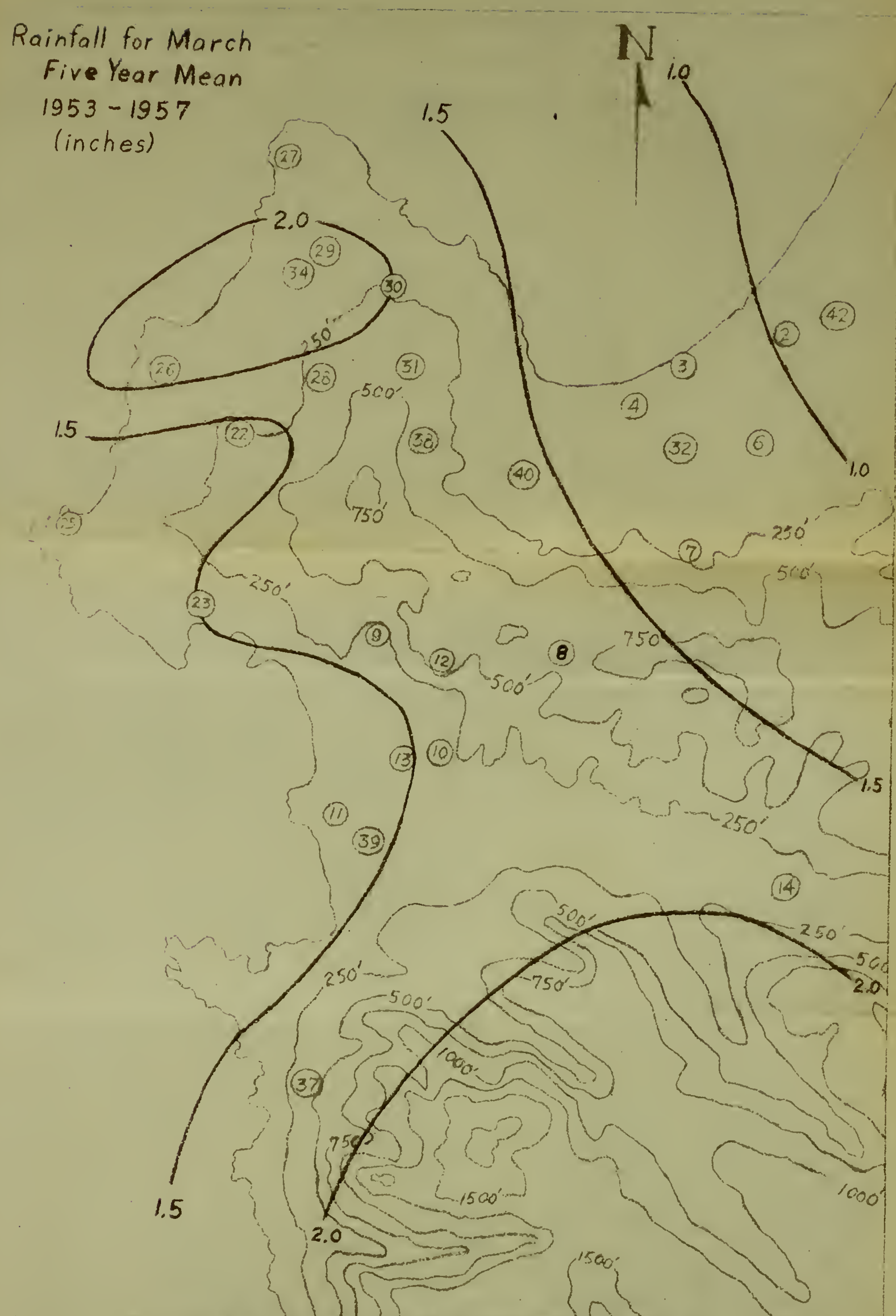


FIGURE 14. ISOHYET CHART FOR MARCH, FIVE-YEAR MEAN

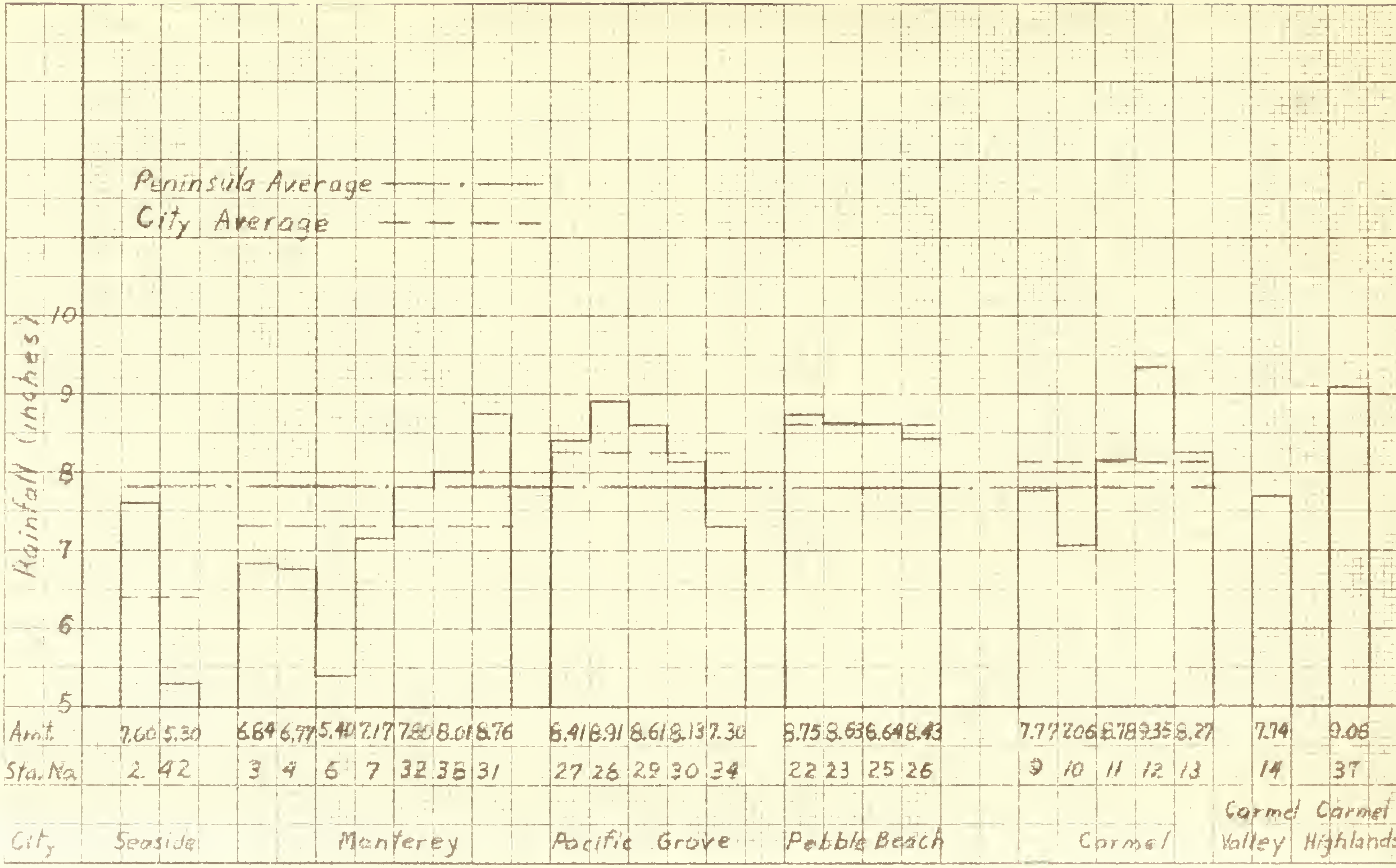


FIGURE 15. PRECIPITATION TOTALS FOR MARCH, 1958

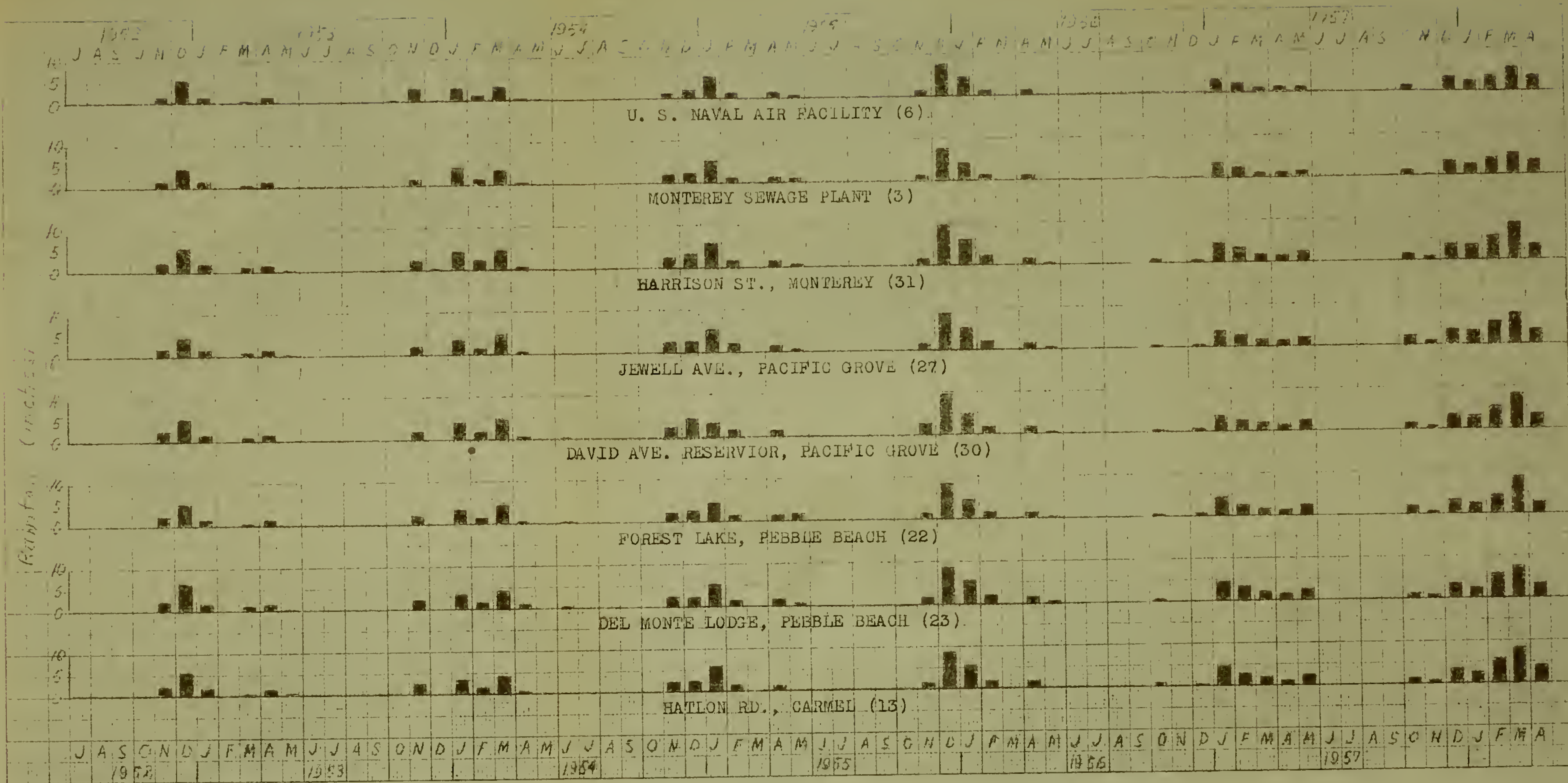


FIGURE 16. MONTHLY PRECIPITATION RECORDS

FIGURE 17. ISOHYET CHART OF FIVE-YEAR SEASONAL PRECIPITATION

for Carmel Highlands (No. 37) seemed reasonable from the results of the individual storms, weekly total, and monthly total analyses previously described. The individual values of seasonal means are graphed in Fig. 18 showing the Peninsula average and the deviations. Fig. 19 is a graph of the Peninsula average for each of the five seasons with the five-year average super-imposed. The very wet season of 1955-1956 raised the five-year average above all of the other four years, which points out again how a high seasonal total can affect a five-year mean. Obviously one high value will not affect a very long-term mean as drastically as it does a short-term mean. However, if a ten-year period is chosen and includes the 1957-1958 season as well, at least two high seasons will be included, affecting the ten-year mean in approximately the same manner. From the seasonal totals as recorded in Carmel Valley (No. 14), the season of 1951-1952 (31.50 inches) was almost double the five-year seasonal average (16.86 inches), so that a ten-year period from July 1947 through June 1957 would include two high years and two low years. However, the high years varied further from the mean (13.55 inches and 4.70 inches) than did the low years (3.85 inches and 3.92 inches), thus resulting in a higher average.

e. Representativeness. In most climatological studies, the reports of one station are taken as representative of a city or area. Therefore, the question arises as to how representative of an area is one report. The reports of

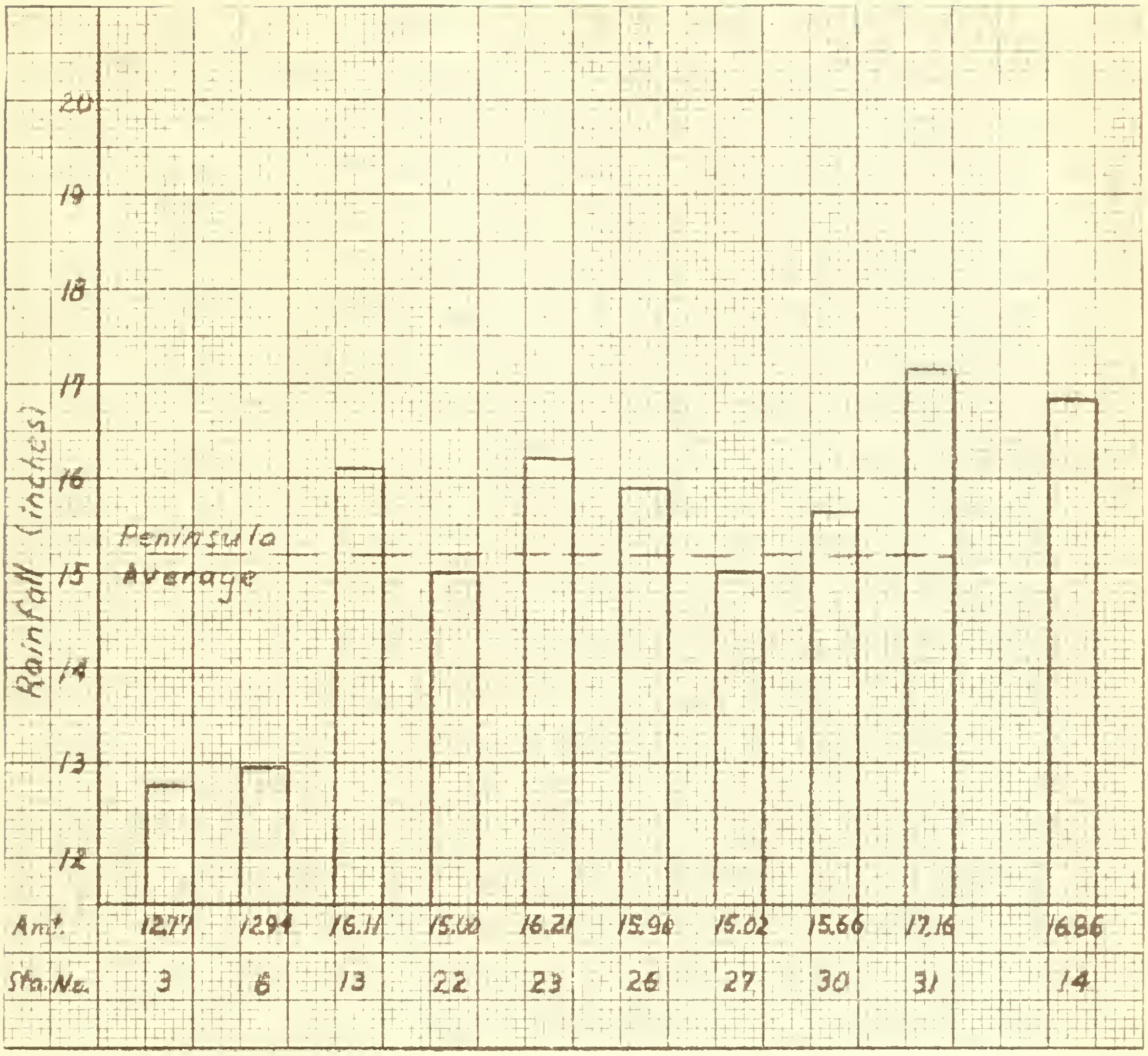


FIGURE 18. FIVE-YEAR MEAN SEASONAL PRECIPITATION

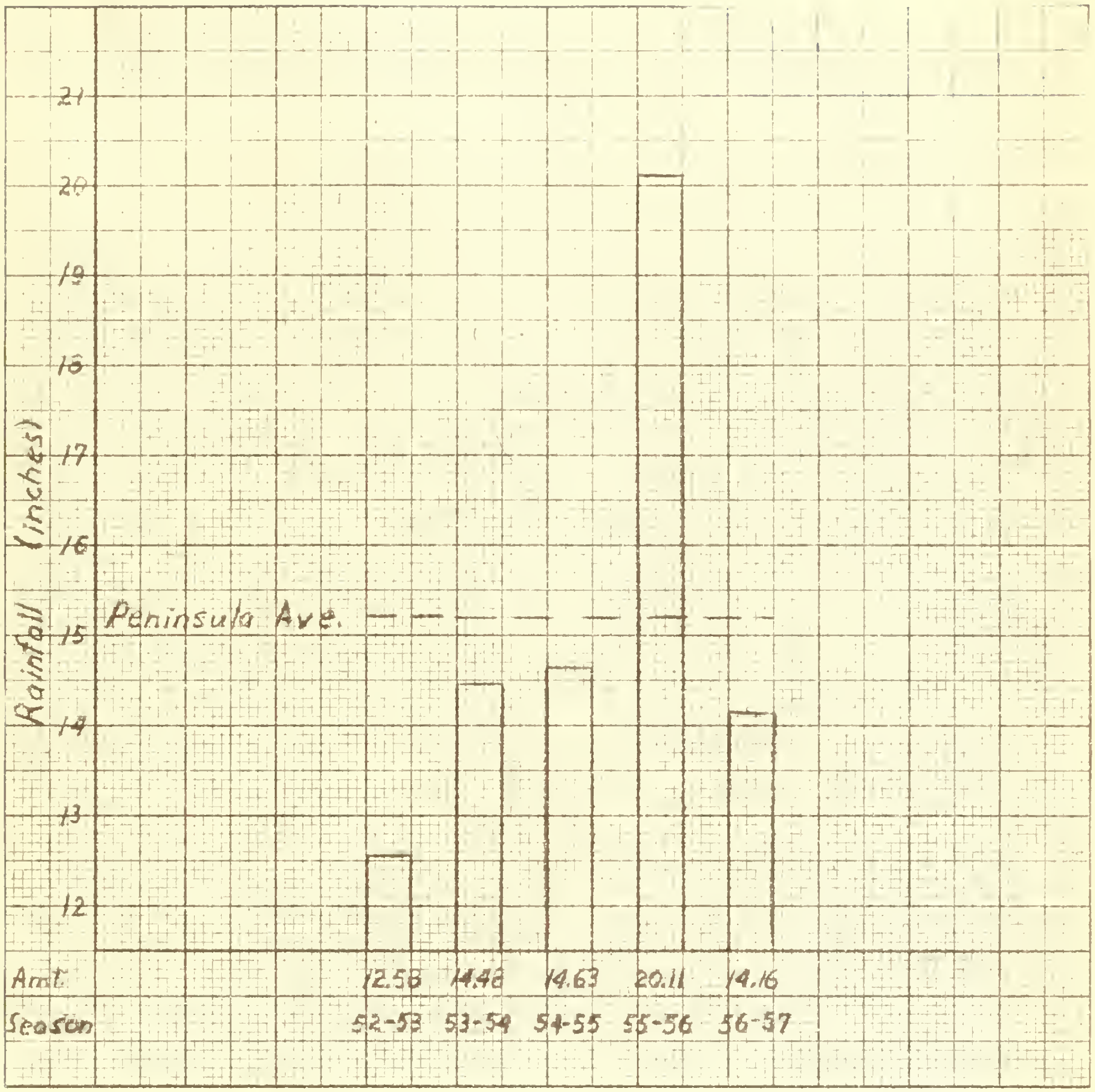


FIGURE 19. PENINSULA AVERAGE FOR FIVE SEASONS

station No. 31 are those used by the United States Weather Bureau in the preparation of the California Climatological Summary. The USNAF (No. 6) is the official synoptic reporting station for the area. A comparison of the individual reports to the Peninsula averages for the various periods indicated that station No. 30 in Pacific Grove reported very close to the average. Table IV lists the three stations with their percent deviation from the Peninsula average for the various periods. It is evident from this table that the USNAF is the least representative of the three stations as their reports are consistently 12 percent to 69 percent below the Peninsula average for the same periods. This is as should be expected, due to the location of USNAF on the lee side of the Peninsula ridge with respect to the prevailing winds. Station No. 31 deviated from 100 percent below to 25 percent above the average for the Peninsula. Station No. 30 deviated from 75 percent below to 17 percent above the average. In all cases, the largest deviations occurred for individual storms, which emphasizes the local variations of these storms.

The deviations for March, 1958 were -30.8 percent for station No. 6, +3.8 percent for station No. 30, and +12.8 percent for station No. 31. Deviations for the seasons are smaller and better represent the likelihood of the station to receive a rainfall near the Peninsula average. From those values, it is evident that station No. 31, a cooperative observer for the Weather Bureau, reports precipitation values from 10 percent to 16 percent above averages for the Penin-

Table IV. Station Variances from Peninsula Average

Station	3 March Total	3 March Dev.	5 March Total	5 March Dev.	7 March Total	7 March Dev.	Week Total	Week Dev.	March Total	March Dev.
USNAF (6)	0.11	-69.4%	0.05	-37.5%	0.06	-50.0%	4.07	-18.0%	5.40	-30.8%
Pacific Grove (30)	0.42	+16.7%	0.02	-75.0%	0.06	-50.0%	4.77	- 4.6%	8.13	+ 3.8%
Monterey (31)	0.45	+25.0%	0.05	-37.5%	0.08	-33.3%	4.71	- 6.0%	8.76	+12.8%
Peninsula Av.	0.36		0.08		0.12		5.08		7.74	

S E A S O N

Station	52-53 Total	52-53 Dev.	53-54 Total	53-54 Dev.	54-55 Total	54-55 Dev.	55-56 Total	55-56 Dev.	56-57 Total	56-57 Dev.
USNAF (6)	11.11	-11.7%	12.63	-12.8%	12.49	-14.6%	17.20	-14.5%	11.26	-20.5%
Pacific Grove (30)	13.21	+ 5.0%	14.98	+ 3.5%	14.08	- 3.8%	21.79	+ 8.4%	14.22	+ 0.4%
Monterey (31)	14.16	+12.6%	16.37	+13.1%	16.22	+10.1%	22.58	+12.3%	16.46	+16.2%
Peninsula Av.	12.58		14.48		14.63		20.11		14.16	

5 YR. SEASONAL AVERAGE

Station	Total	Dev.
USNAF (6)	12.94	-14.9%
Pacific Grove (30)	15.66	+ 3.0%
Monterey (31)	17.16	+12.9%
Peninsula Average	15.20	

sula, which means the values quoted in the California Climatological Summary are approximately 13 percent in excess of the actual average precipitation for the Peninsula. Station No. 30, however, reports within three percent to nine percent of the Peninsula average, either above or below. The USNAF reports from twelve percent to 20 percent below, or an average of 15 percent below the Peninsula average. Sufficient data are not available to determine stations which are representative of each city. The seasonal totals are limited to one or two stations in each city.

The Extended Forecast Section of the Weather Bureau publishes a bulletin [6] semimonthly in which the 30-day outlook is given. Precipitation values are given in terms of light, moderate, or heavy with respect to the 20-year normal for each station for the particular forecast period. These normal values are represented by two class limits, one dividing the light from the moderate, the other dividing the moderate from the heavy. The class limits for the forecast period are plotted for the stations on a chart included in the forecast. As an example, the limits for monthly precipitation amounts from mid-May to mid-June for San Francisco are 0.09 and 0.37 inches. The predicted precipitation for the San Francisco area is moderate, therefore, from 0.09 to 0.37 inches may be expected between mid-May to mid-June, 1958.

With reference to these forecasts, class limits were determined for a station in Pacific Grove. This station was

used because it is the only one for which a 20-year record of monthly values (1929 to 1948 for January through May and 1929 through 1947 for June through December) was available. The class limits are obtained by listing the monthly value for each year in numerical order and dividing the number of values in three parts. The two values at the division points are the class limits for that month. The class limits which divide the light precipitation from moderate and moderate from heavy precipitation for Pacific Grove are listed in Table V. These limits should be close to the Peninsula average limits as station No. 30 in Pacific Grove was very close to the average for the Peninsula.

f. County Precipitation. Of the eight observers located within Monterey County but not on the Monterey Peninsula (Table III), only the station at Moss Landing (No. 1) reports less precipitation than the Peninsula average. The coast is flat with no orographic barriers near the station. The remaining seven observers are located in mountainous terrain. San Clemente Dam (No. 18) and Los Padres Dam (No. 19) are located in the Santa Lucia mountains near the head waters of the Carmel River. Stations numbered 20, 21, and 50 are located near the Coast Highway in the Santa Lucia Mountain Range. These higher elevations with large orographic features receive heavier rainfall than that experienced by the Peninsula. For example, San Clemente Dam (No. 18) reports 19.82 inches for the five-year seasonal mean, Los Padres Dam (No. 19) reports 22.18 inches, and Bixby Mountain

Table V. Normal Precipitation Class Limits

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	HEAVY PRECIPITATION											
Upper Class Limit	4.53	420 3.87	3.92	1.12	0.69	0.20	0.00	0.02	0.07	1.02	1.33	4.08
	MODERATE PRECIPITATION											
Lower Class Limit	3.00	2.74	1.46	0.45	0.25	0.03	0.00	0.00	0.00	0.45	0.40	1.90
	LIGHT PRECIPITATION											

(No. 50) reports 33.96 inches as compared to the Peninsula five-year seasonal mean of 15.20 inches. The individual storms and monthly total also indicate the same variations (Table VI) except for the storm of 3 March, 1958. This storm did not extend beyond the Santa Lucia Mountain Range as evidenced by the heavy precipitation recorded along the coast (0.57 inches to 0.90 inches) while the dams (Sta. No. 18 and 19) did not receive even a trace of precipitation.

Table VI

County Precipitation Records

Sta. No.	3 Mar	5 Mar	7 Mar	Week 31 Mar - 6 Apr	Month March
1	0.07	0.0	0.09	3.50	6.41
18	0.0	0.43	0.10	8.50	9.38
19	0.0	0.50	0.11	8.83	10.48
20	0.90	0.11	0.17	6.48	14.25
21	0.76	0.40	0.30	8.25	14.33
50	0.57	0.24	0.25	8.36	18.09

Sta. No.	Seasons 52-53	53-54	54-55	55-56	56-57	5-Yr. Seasonal Mean
18	19.28	16.34	16.99	28.64	17.18	19.82
19	19.[illegible]2	17.35	19.56	32.58	18.04	22.18
50	31.73	26.66	33.72	46.56	31.15	33.96

6. Conclusions

The topography of the Monterey Peninsula has a marked effect on the factors affecting precipitation such as wind and clouds. From the results of this study, certain conclusions have been made.

a. Very low clouds cause heavy precipitation at the base of the ridge on the windward side and decreasing precipitation with increasing elevation. Light precipitation is experienced on the lee side of the ridge.

b. Low clouds cause light precipitation at the base of the ridge on the windward side and increasing amounts with increasing elevation. Light precipitation is experienced on the lee side of the ridge.

c. Higher low clouds cause light precipitation at the base and on the lower slopes of the ridge on the windward side. The heaviest precipitation is experienced at the highest elevations on both the windward and leeward sides. This is due to the wind carrying the precipitation over the ridge where it falls as it loses momentum. Large amounts of rainfall may be observed to leeward of a pass in the ridge if the pass is not sufficiently high to precipitate all the water from the clouds.

d. The most representative station for the Peninsula average is the Pacific Grove Reservoir, operated by the California Water and Telephone Company. This station (No. 30) receives precipitation amounts within three to nine percent of the average precipitation for the

Monterey Peninsula. The climatological reporting station (No. 31) reports 13 percent above the average for the Peninsula and the USNAF (No. 6) reports 15 percent below the Peninsula average.

e. The class limits separating heavy, moderate, and light amounts of precipitation for the Monterey Peninsula were determined for each month in accordance with the Weather Bureau's system for monthly weather forecasts [6].

7. Recommendations

It is believed that a more complete study could be made of the variation of precipitation on the Monterey Peninsula if the information gained from working with this data could be used in increasing the number of observers and improving the accuracy of the reports.

More observers are needed to better delineate the variations of precipitation on the Peninsula. The locations where they would provide the most information are on both slopes of the Carmel Valley, in Carmel Highlands at staggered elevations, in Pebble Beach and Monterey Country Club especially on the side of the ridge, along the top of the ridges, and in Seaside. Some observers at Fort Ord and in Marina would better indicate the variations along the coast.

Better results could be obtained if the observers could be impressed with the importance of proper exposure of their rain gages. It is believed that all observers are conscientious and read their gages accurately, but the exposure of some of the gages is questionable.

Future studies which would be of value in supporting or correcting some of the results obtained would be a comparison of all types of rain gages used by observers. This should be done for all types of precipitation, from light drizzle to a hard downpour, at one location to test the accuracy of each type gage. At the time of this study, only one test-tube gage was available for comparison with other types.

A study of this same type conducted in five years and again in ten years would be very valuable. More observers should be participating and five-year records for as many as 30 stations is not an impossibility. Much more detail could be investigated with such data available.

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